United States Patent [19]

Nilsson

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[45] **Date of Patent: Dec. 8, 1987**

[54] **STRAIGHTENING MACHINES AND METHODS**

[76] Inventor: **Einar W. Nilsson,** 705 E. Curtin St., Bellefonte, Pa. 16823

[21] Appl. No.: **659,087**

[22] Filed: **Oct. 10, 1984**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 280,372, Jul. 6, 1981, Pat. No. 4,494,394.

[51] **Int. Cl.**^{4} **B21D 3/04**

[52] **U.S. Cl.** **72/98;** 72/99

[58] **Field of Search** 72/98, 99, 249

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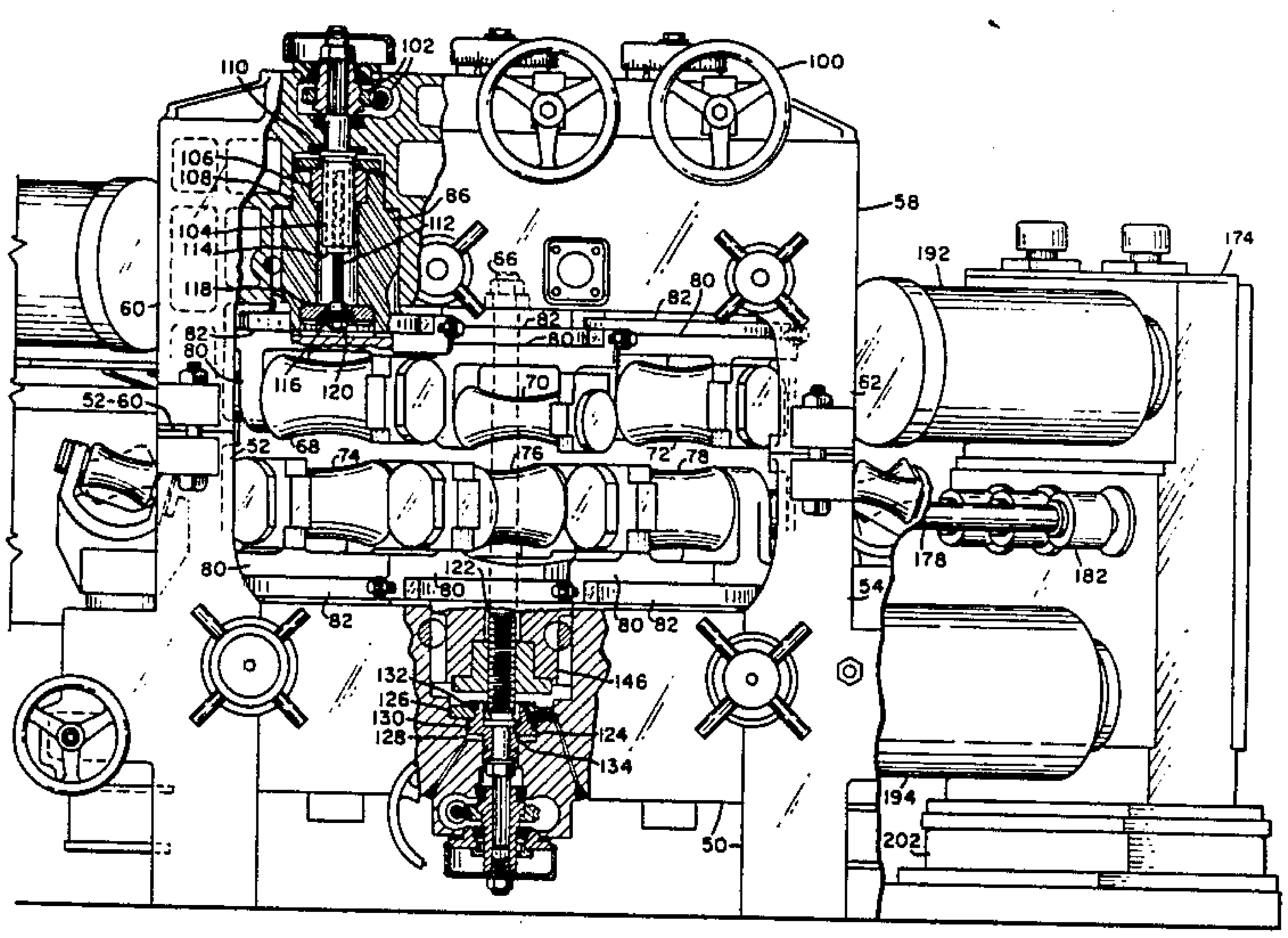
Primary Examiner—Lowell A. Larson

Attorney, Agent, or Firm—Reed Smith Shaw & McClay

[57] **ABSTRACT**

A cross-roll straightener adapted to straighten round metal stock, wire, rods, bars and tubes by rotatingly advancing the stock through a central curved pass such that it is flexed beyond the yield point in a substantially uniform and gradual manner. A three pair roll arrangement provides uniform guidance and flexure while avoiding marking or collapsing of the stock. Also provided is a method for maintaining the stock in the pass line of a cross-roll straightener having a female roll of larger diameter than the male roll.

6 Claims, 33 Drawing Figures



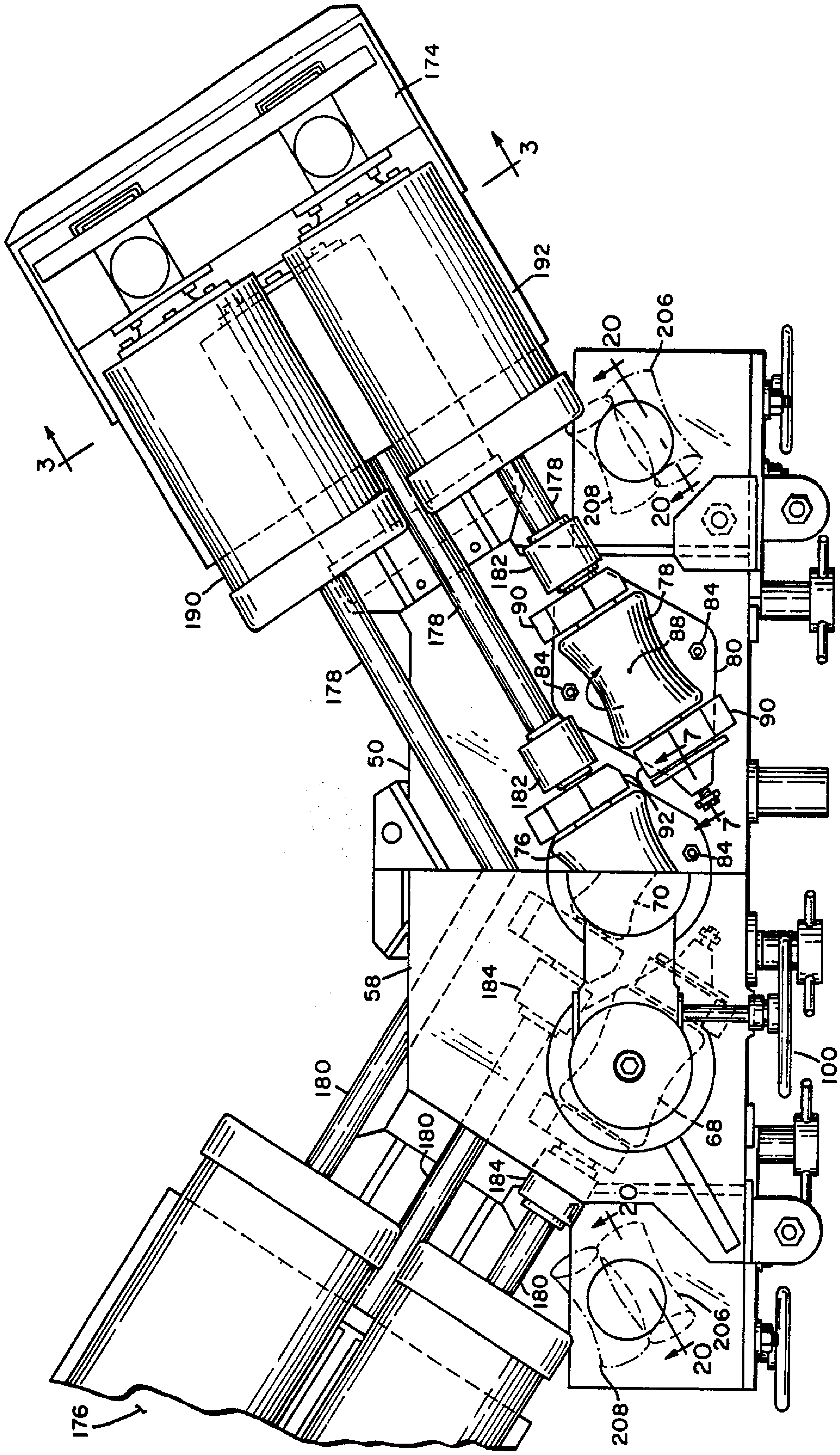

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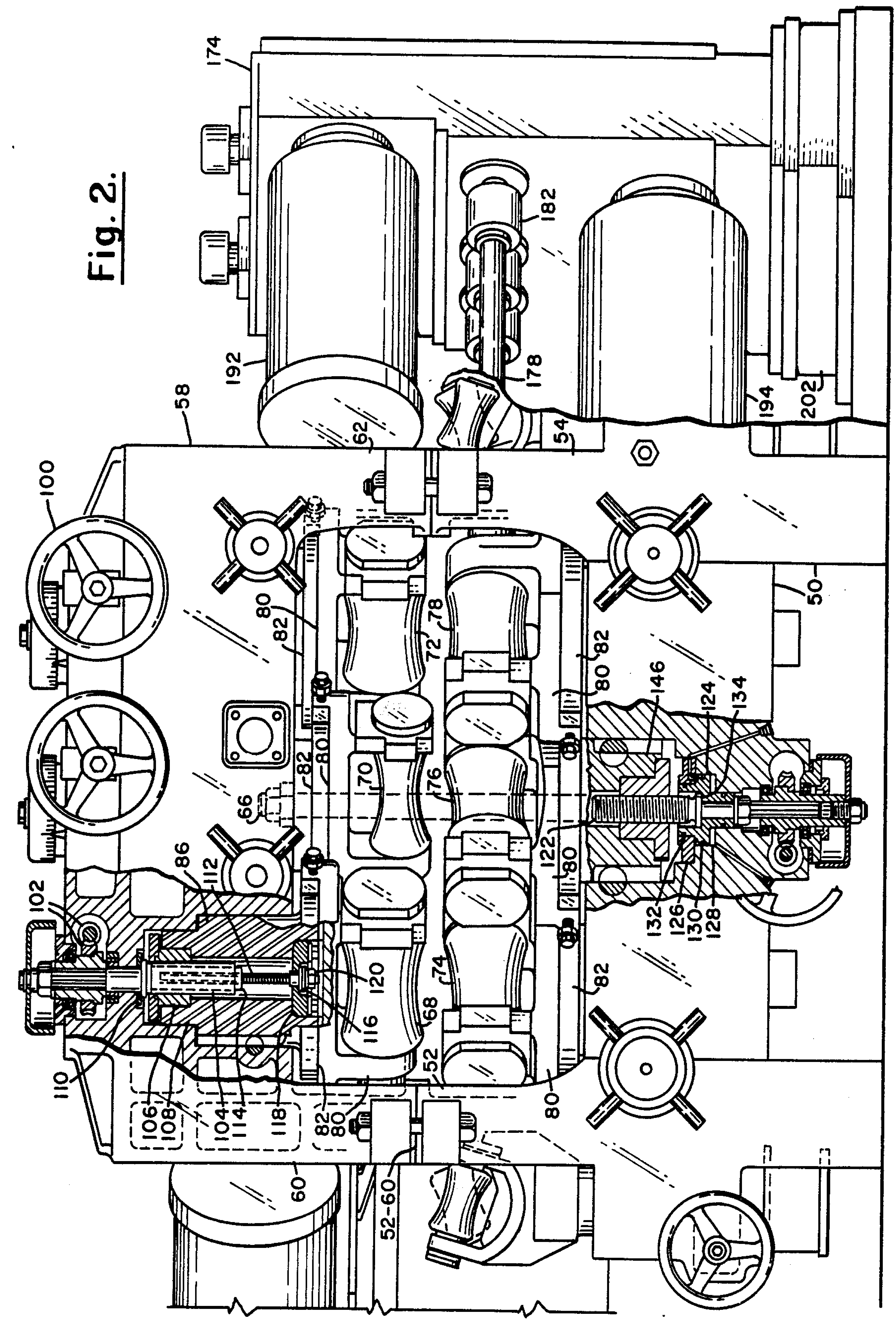
Fig. I.



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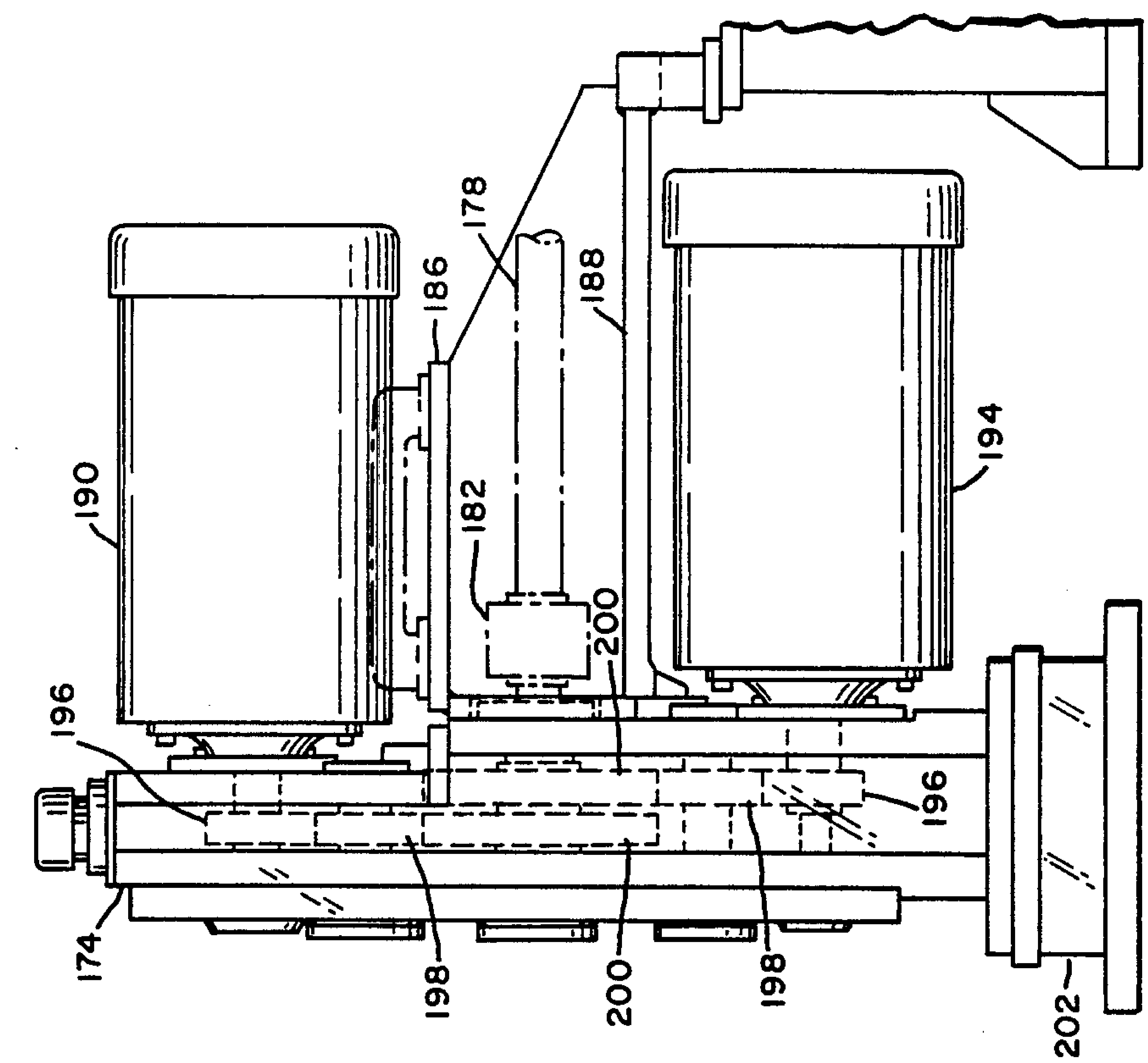

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Fig. 4.

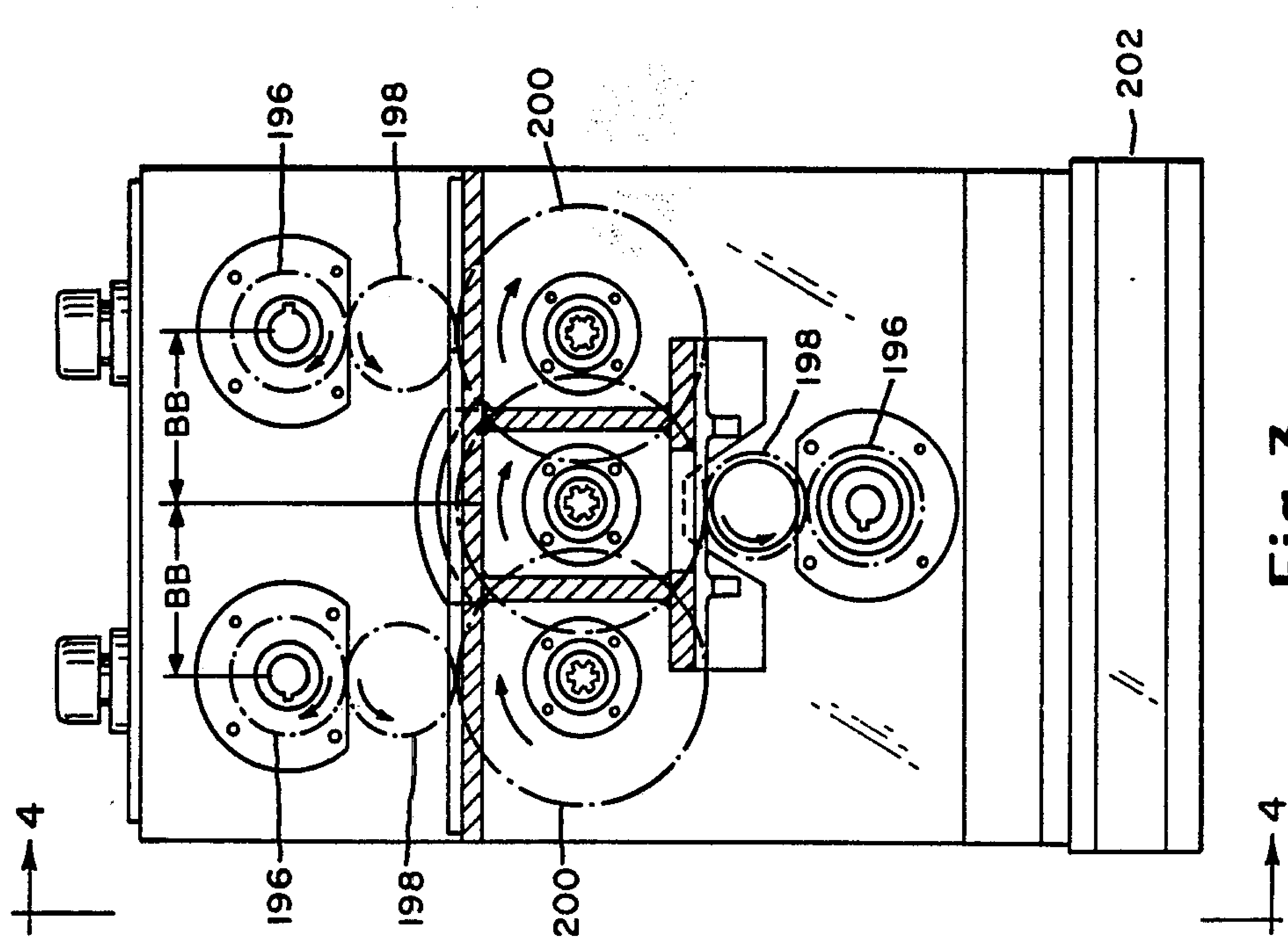

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Fig. 3.

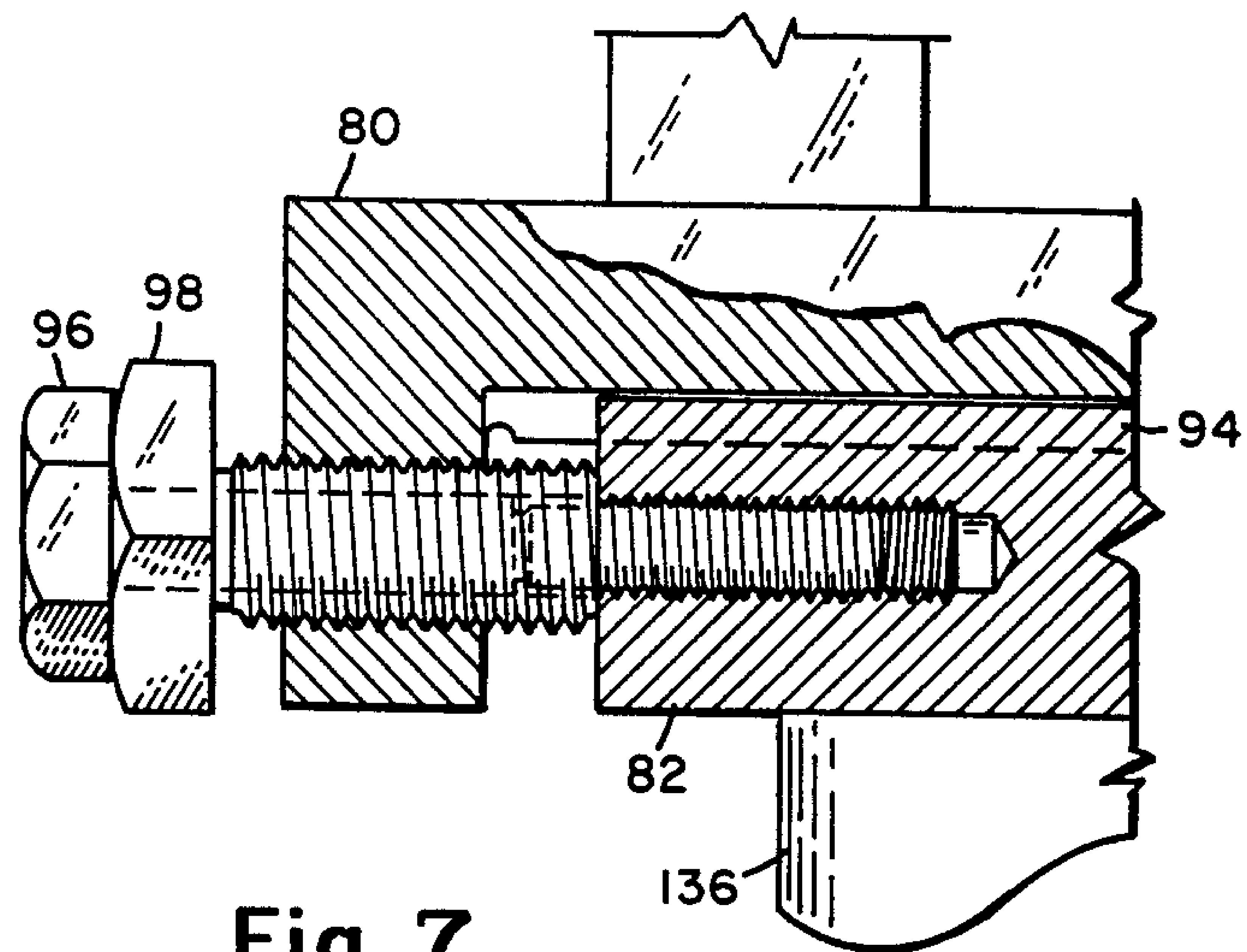
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Fig. 7.

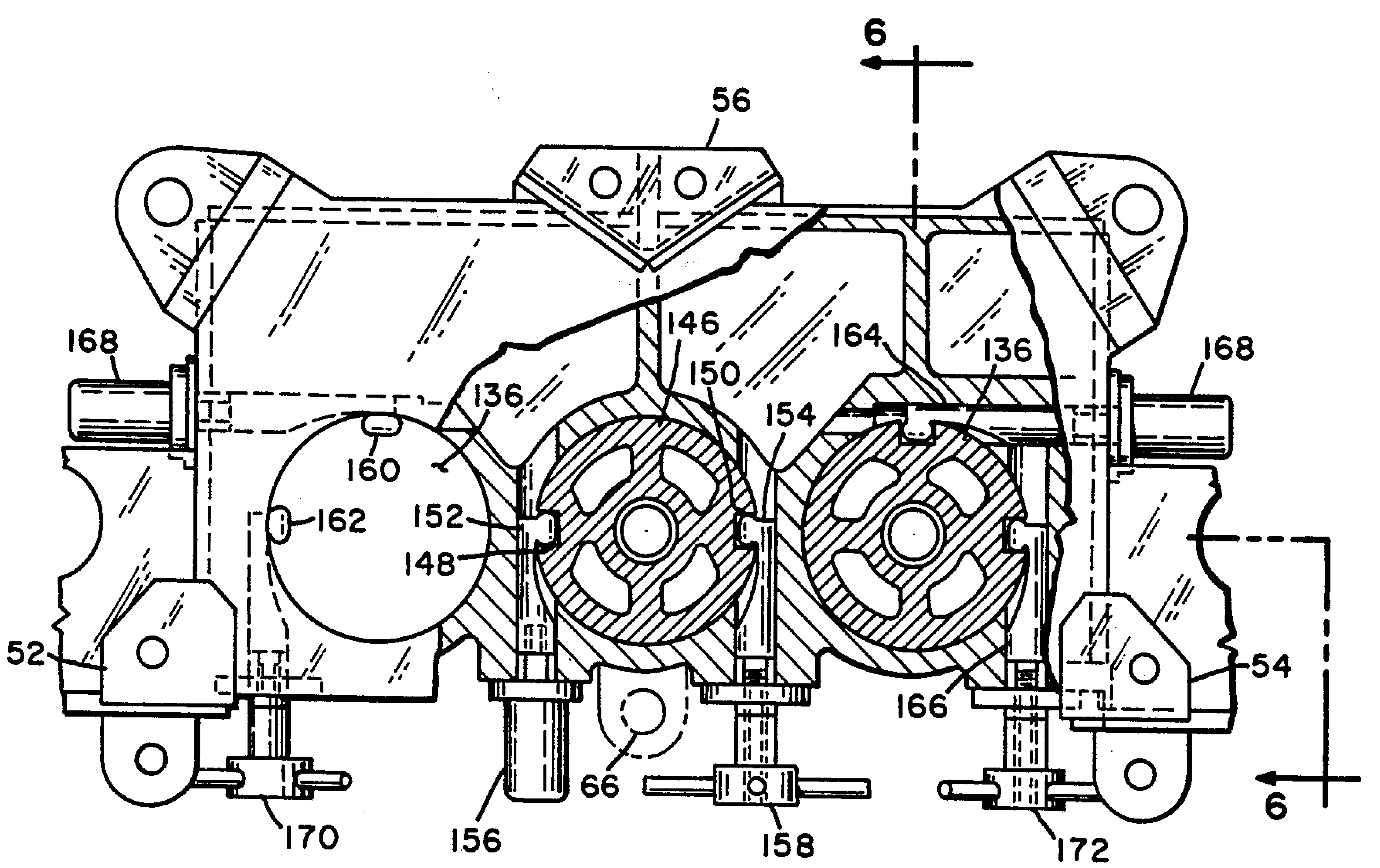
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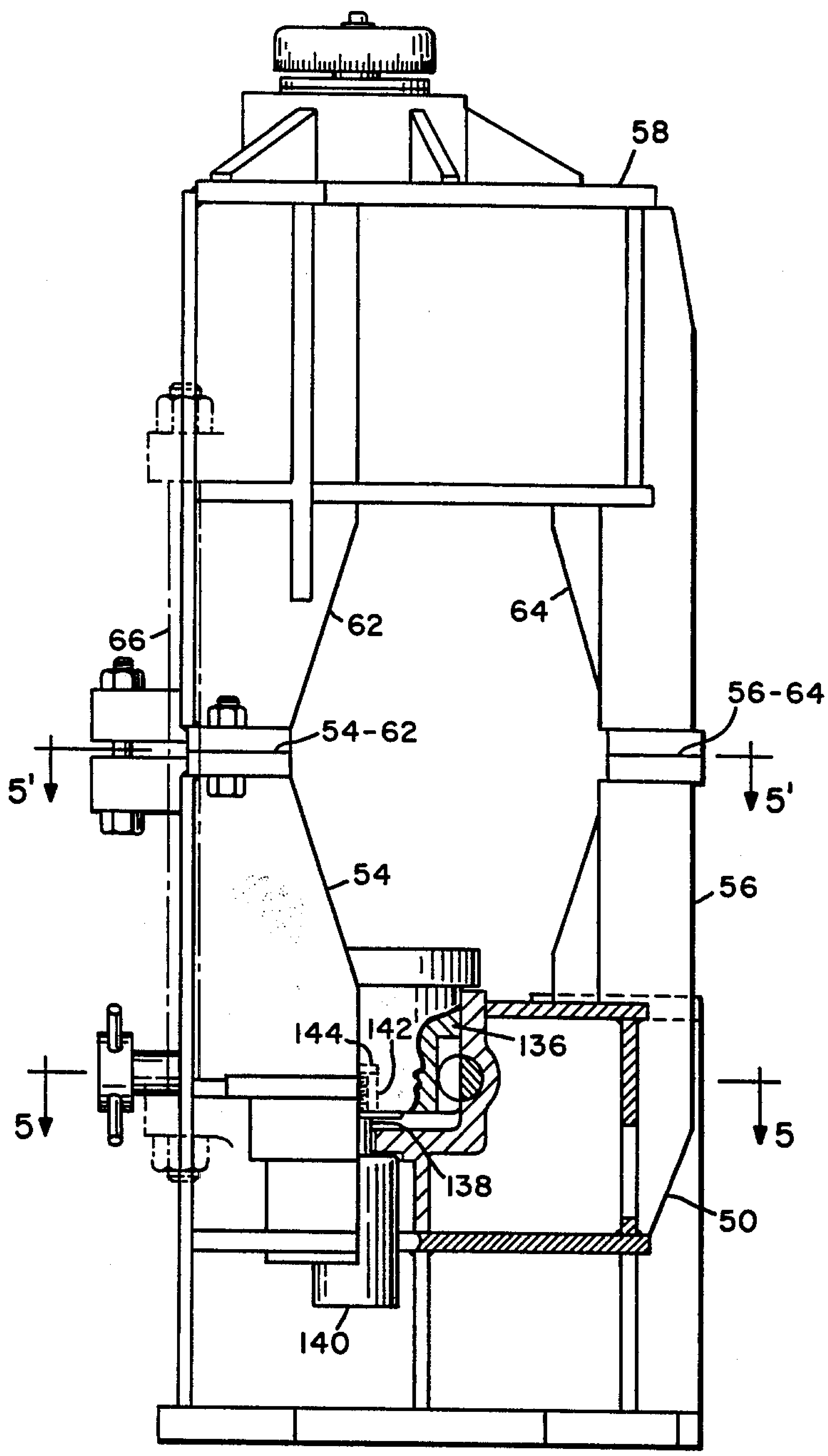
Fig. 5.



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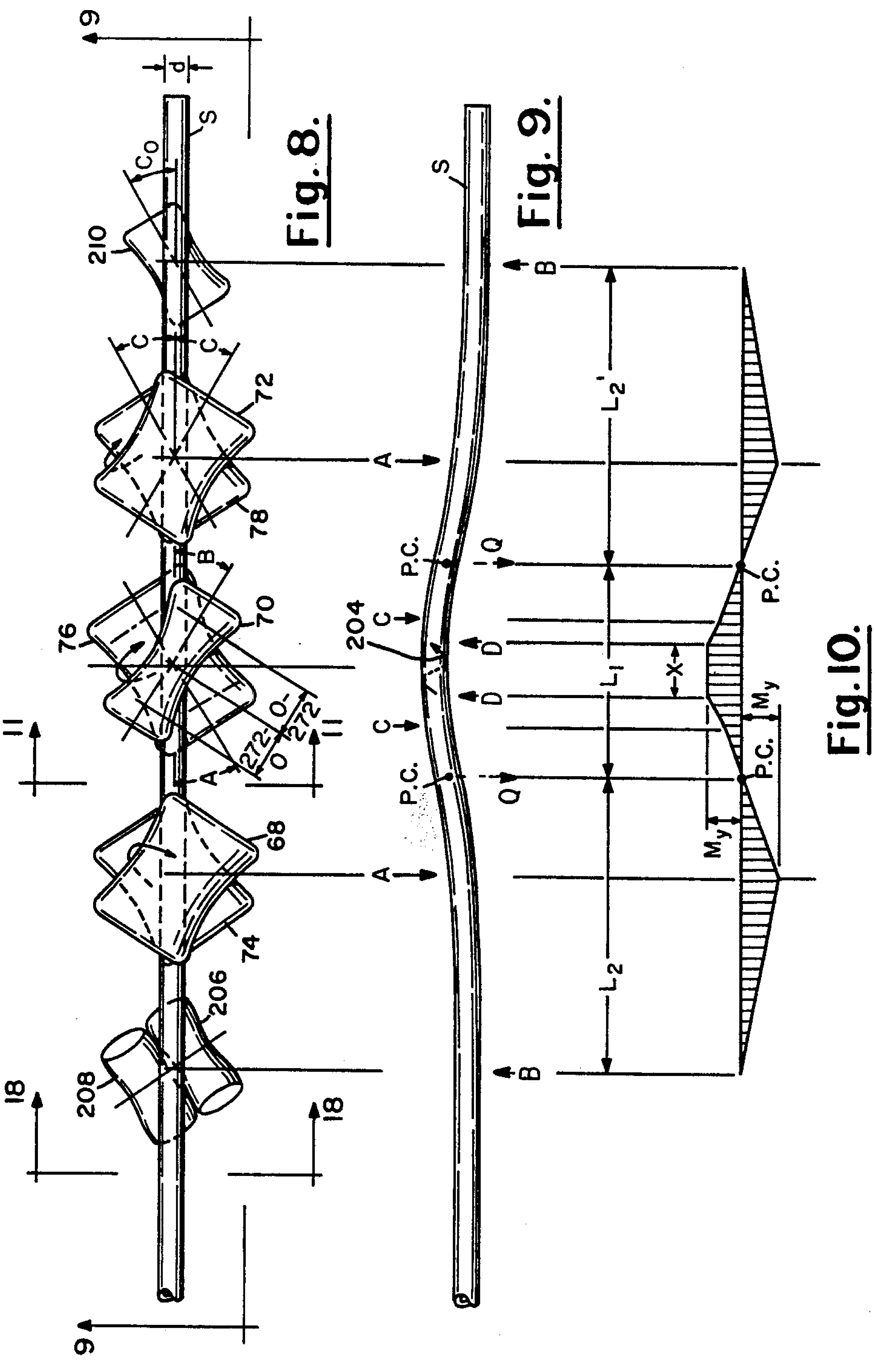
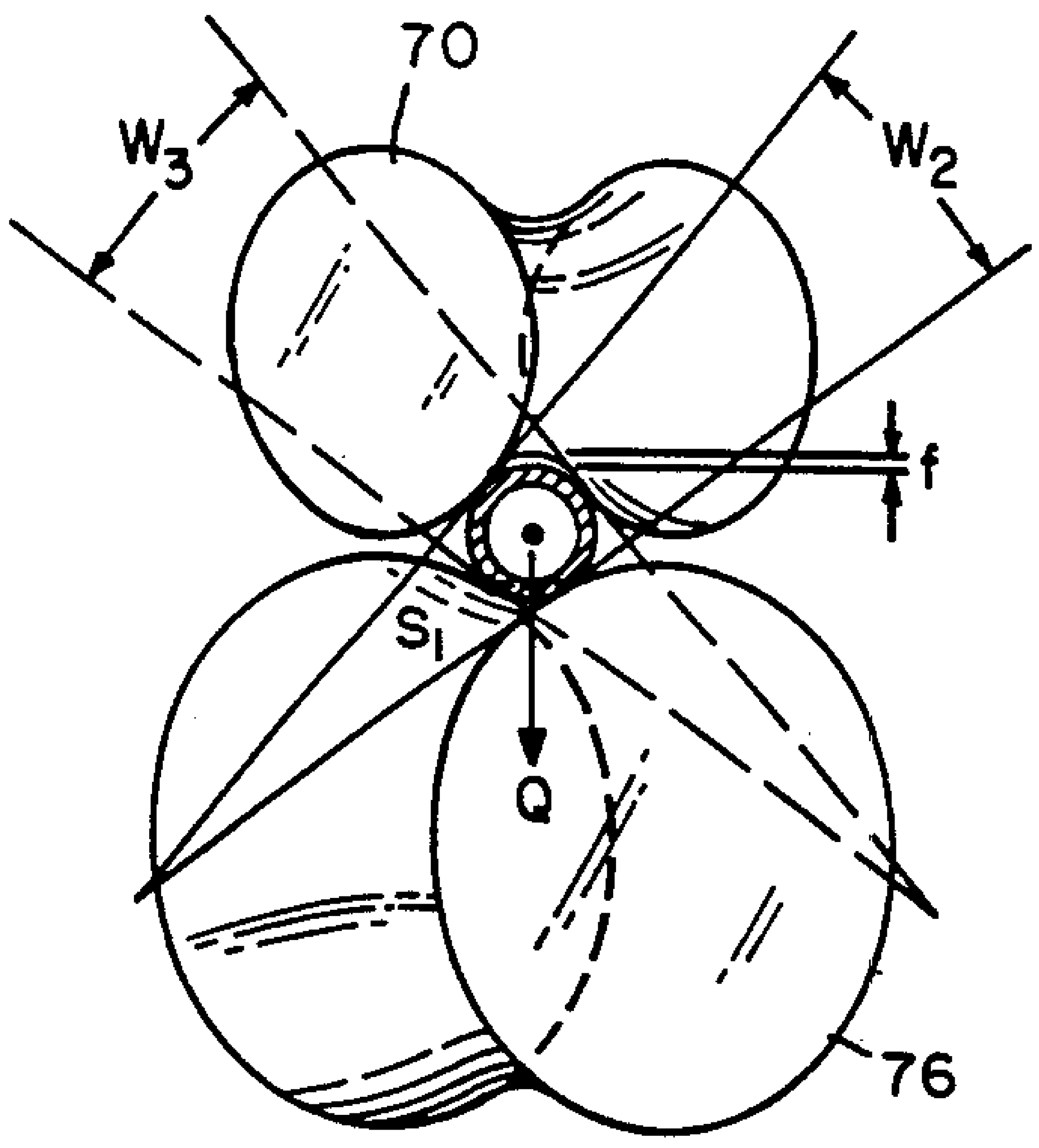


Fig. 8.

Fig. 9.

Fig. 10.



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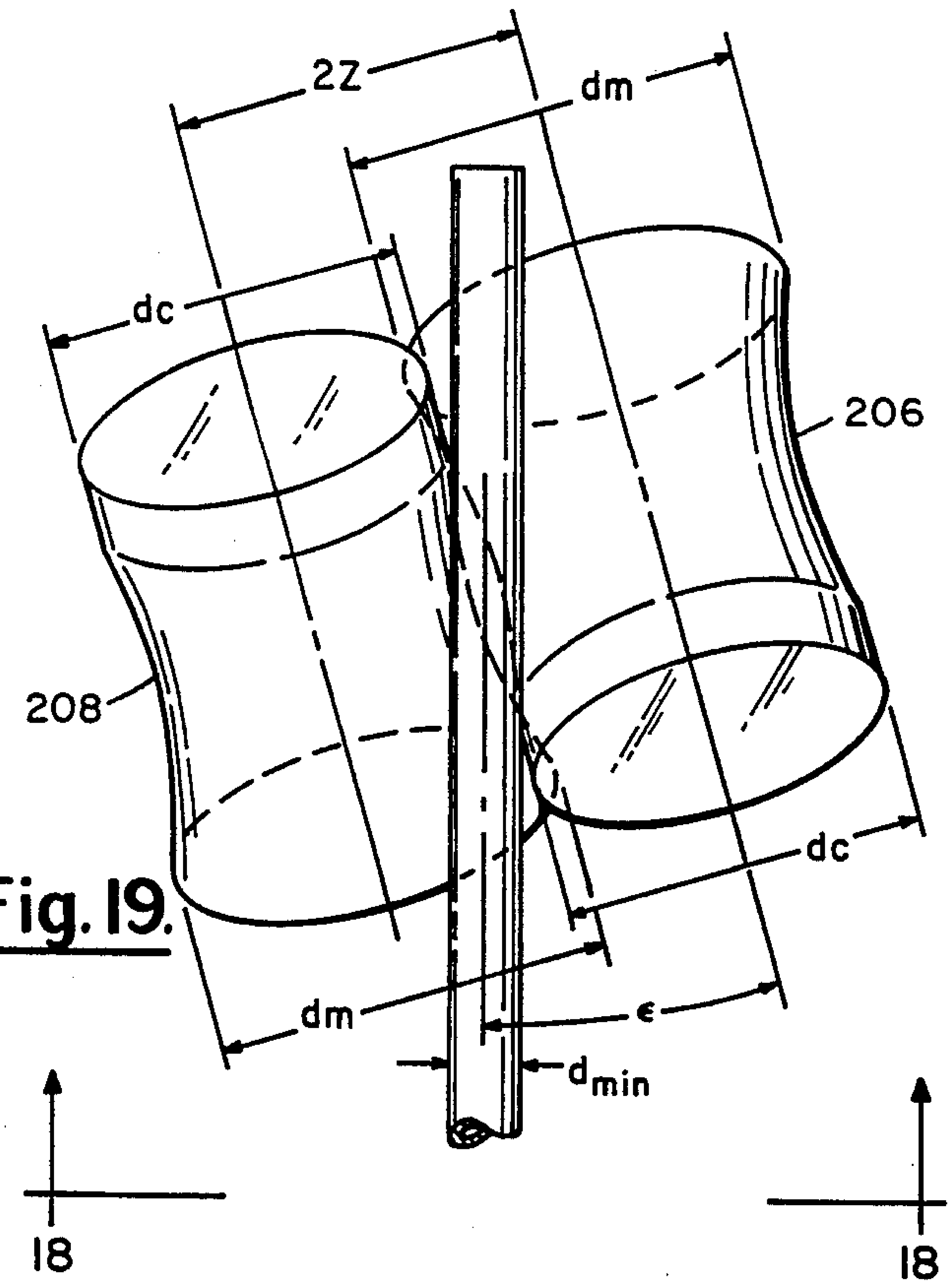

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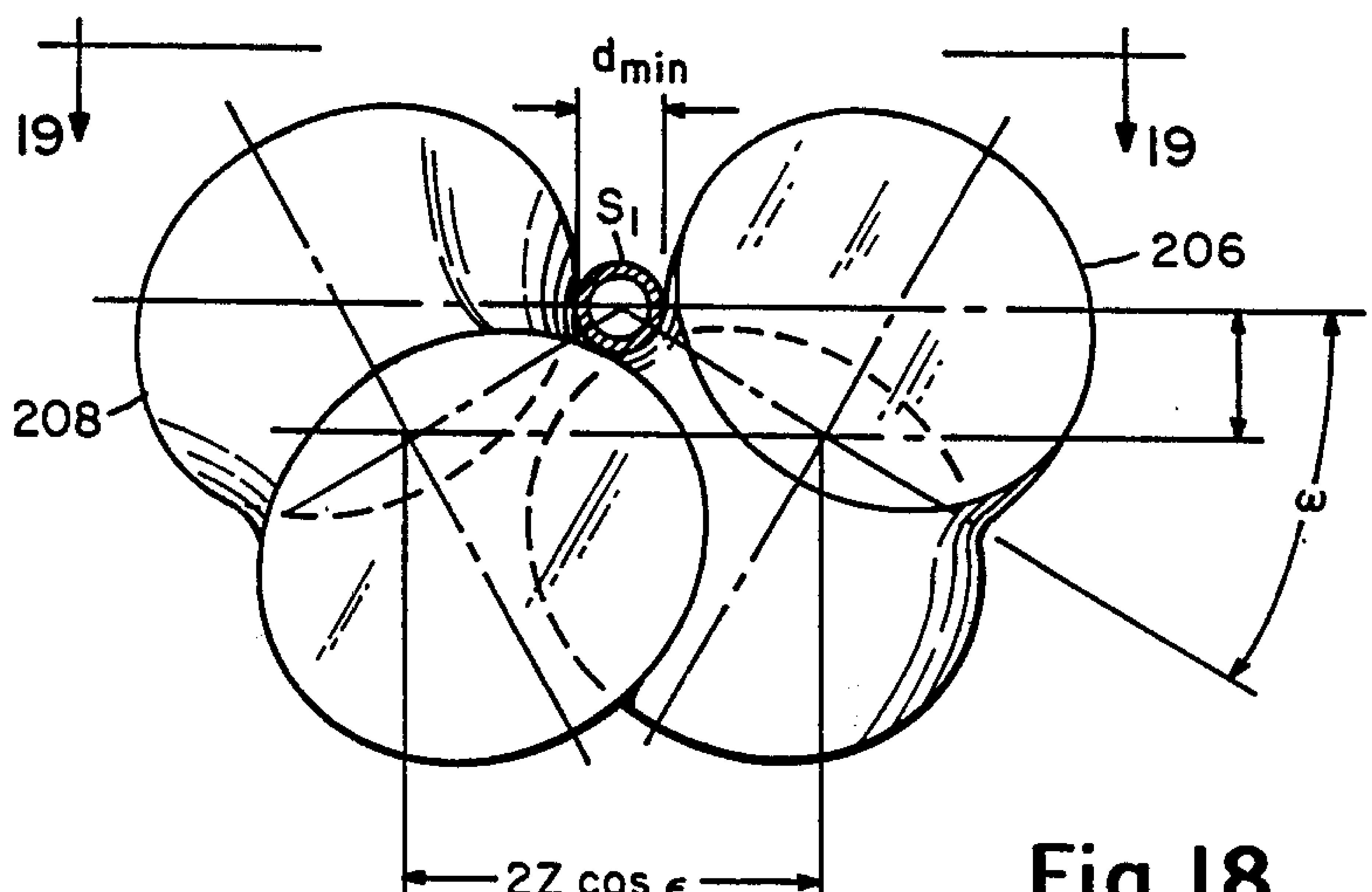

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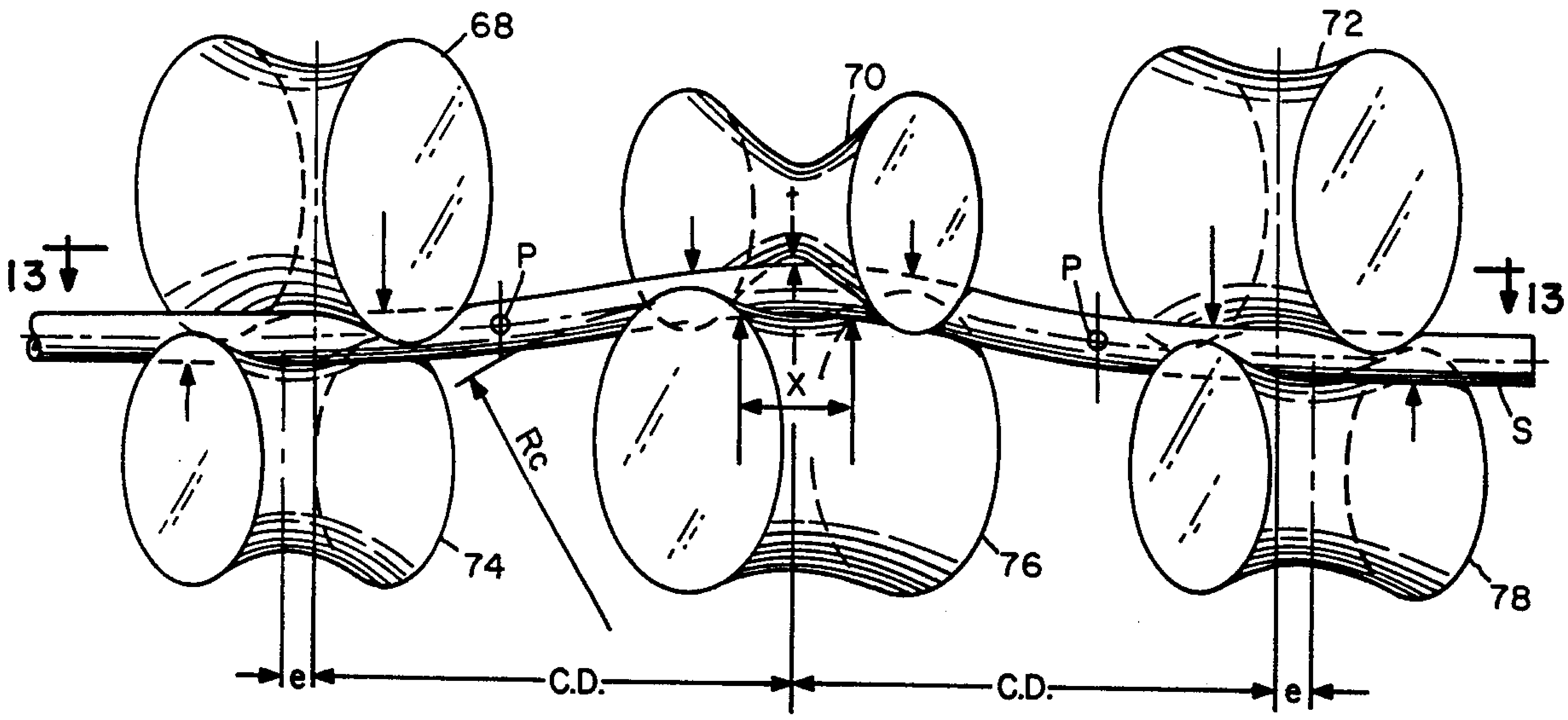

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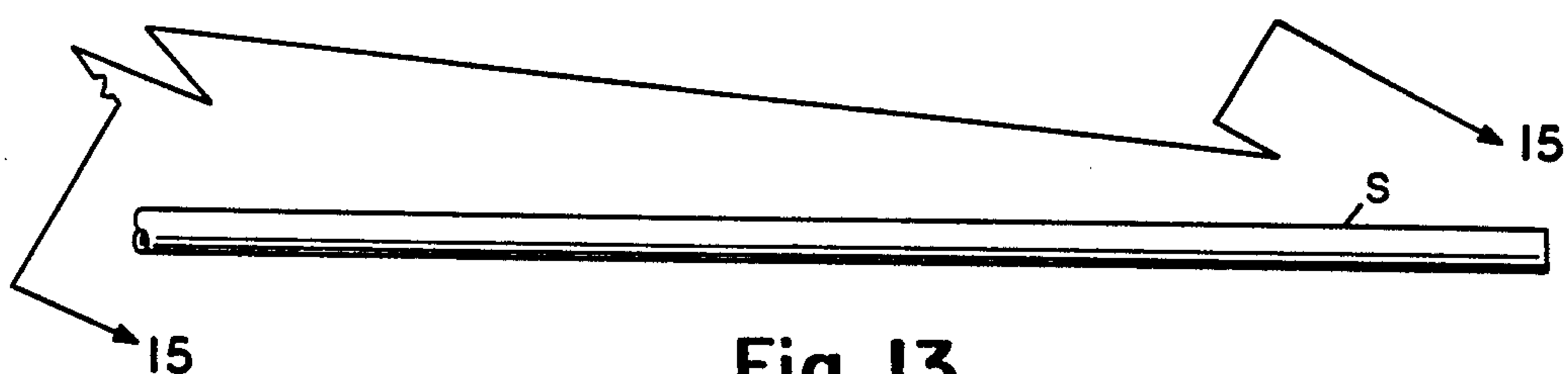

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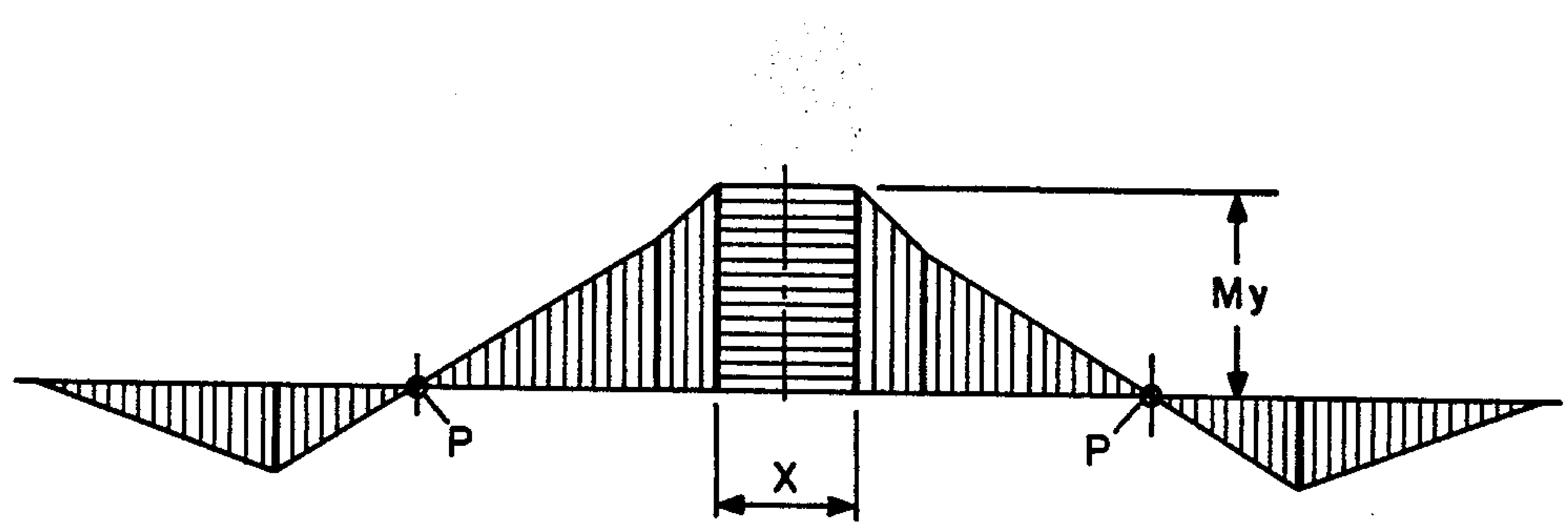

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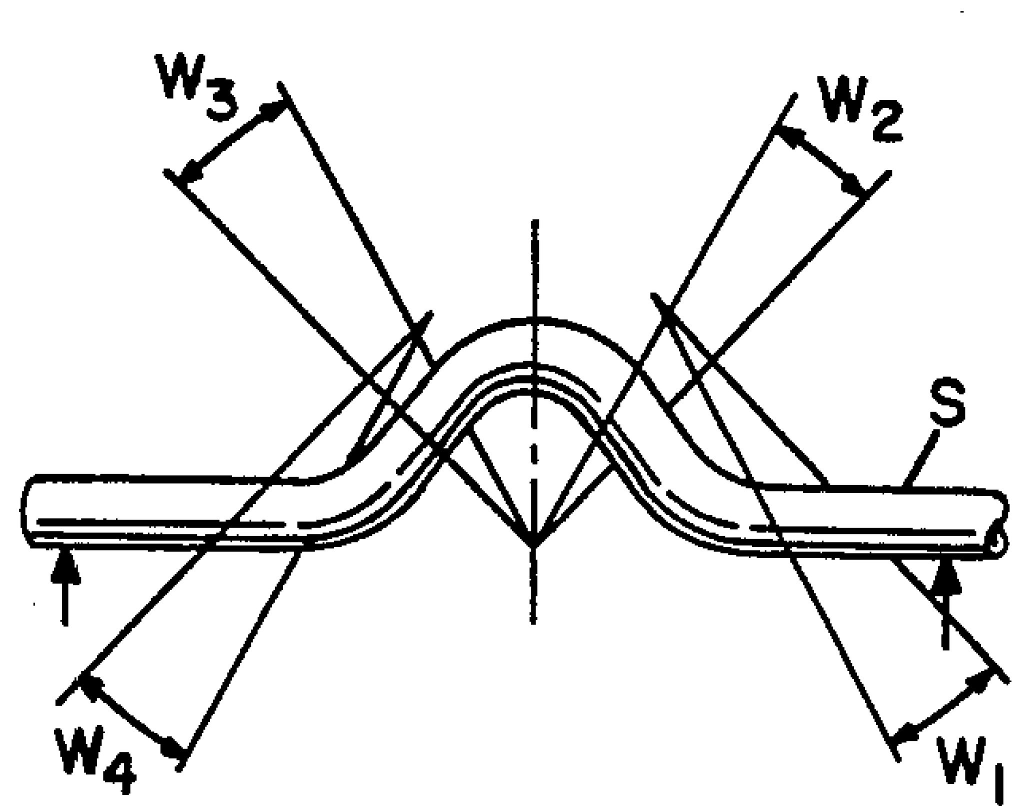

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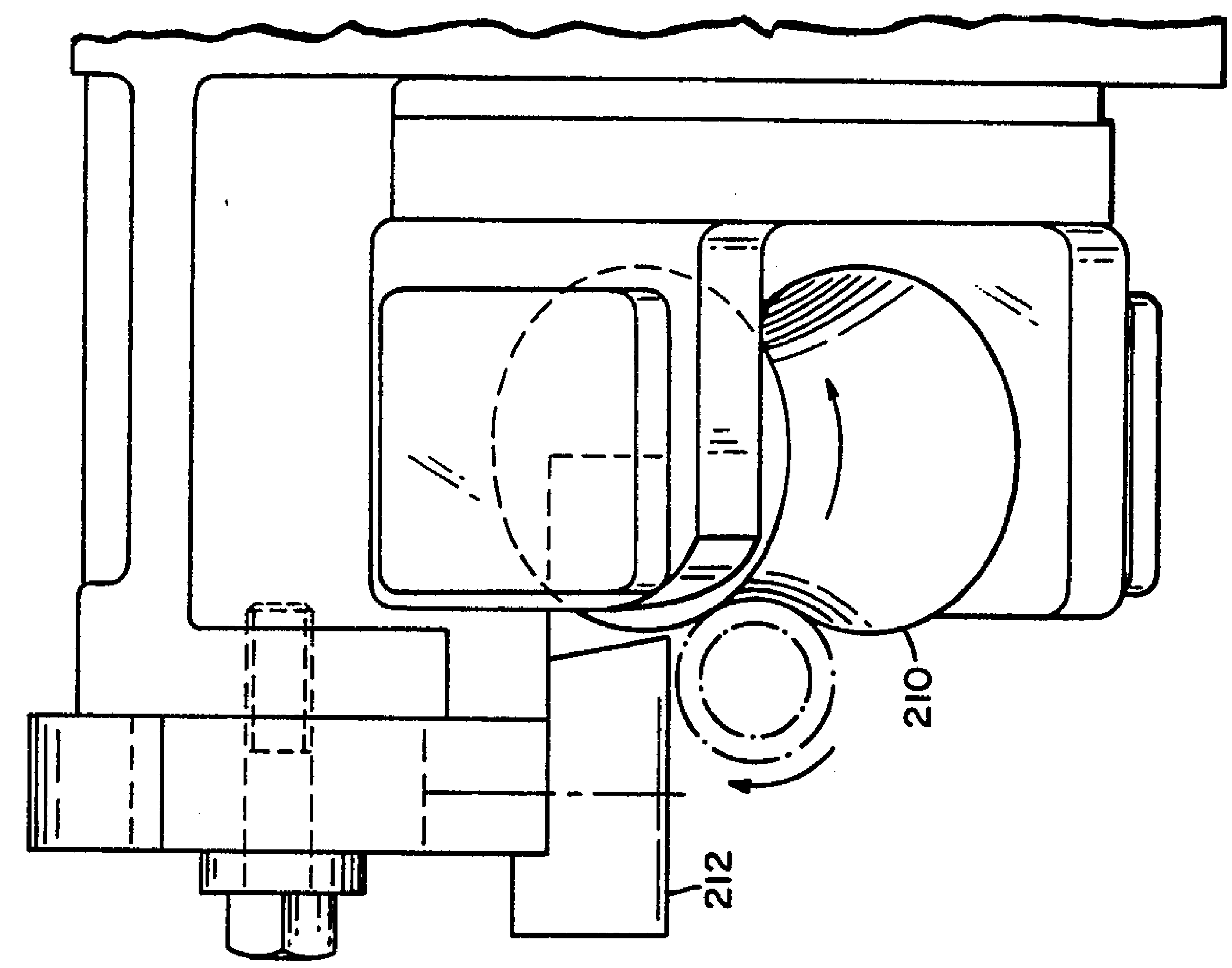

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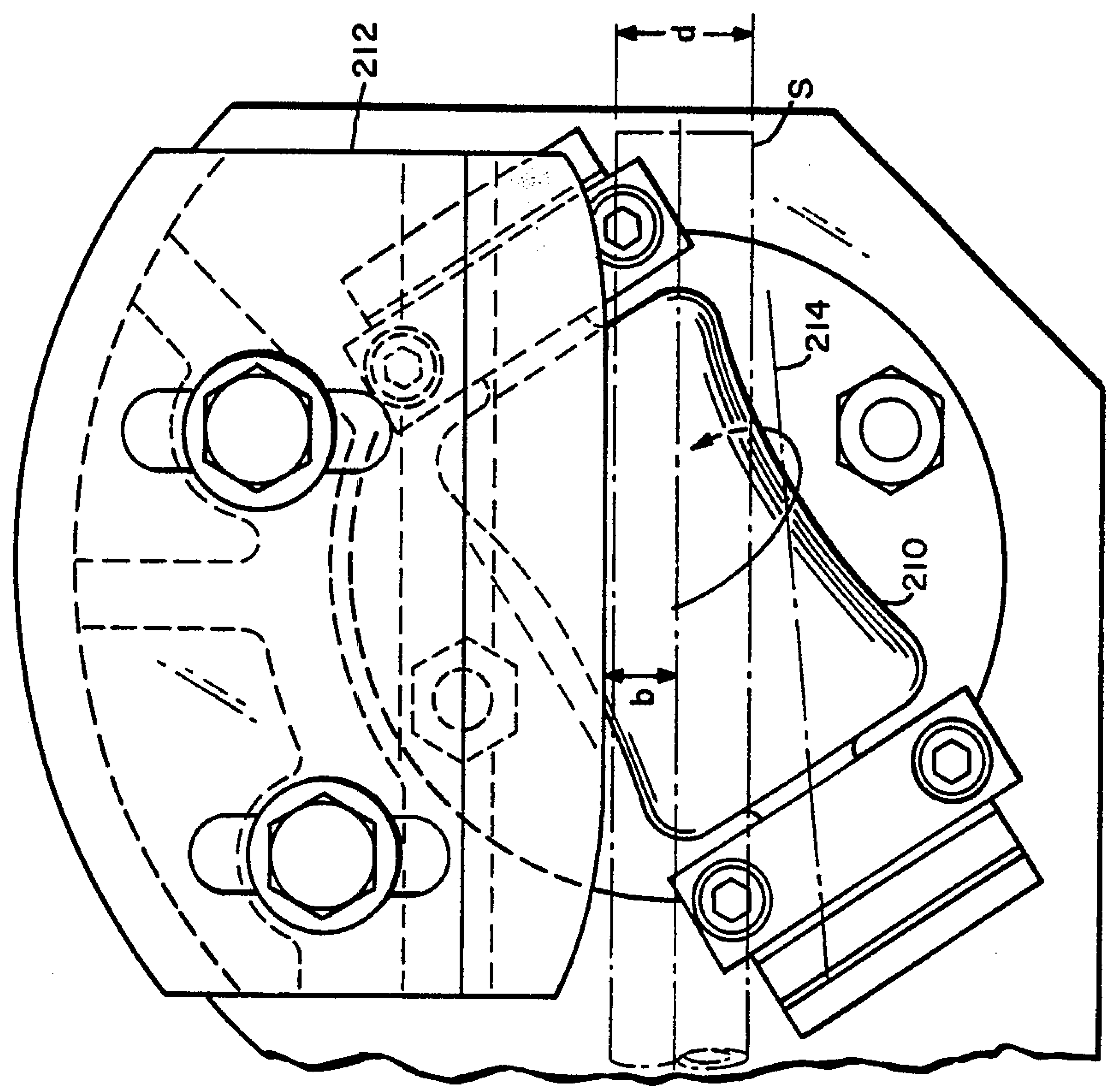

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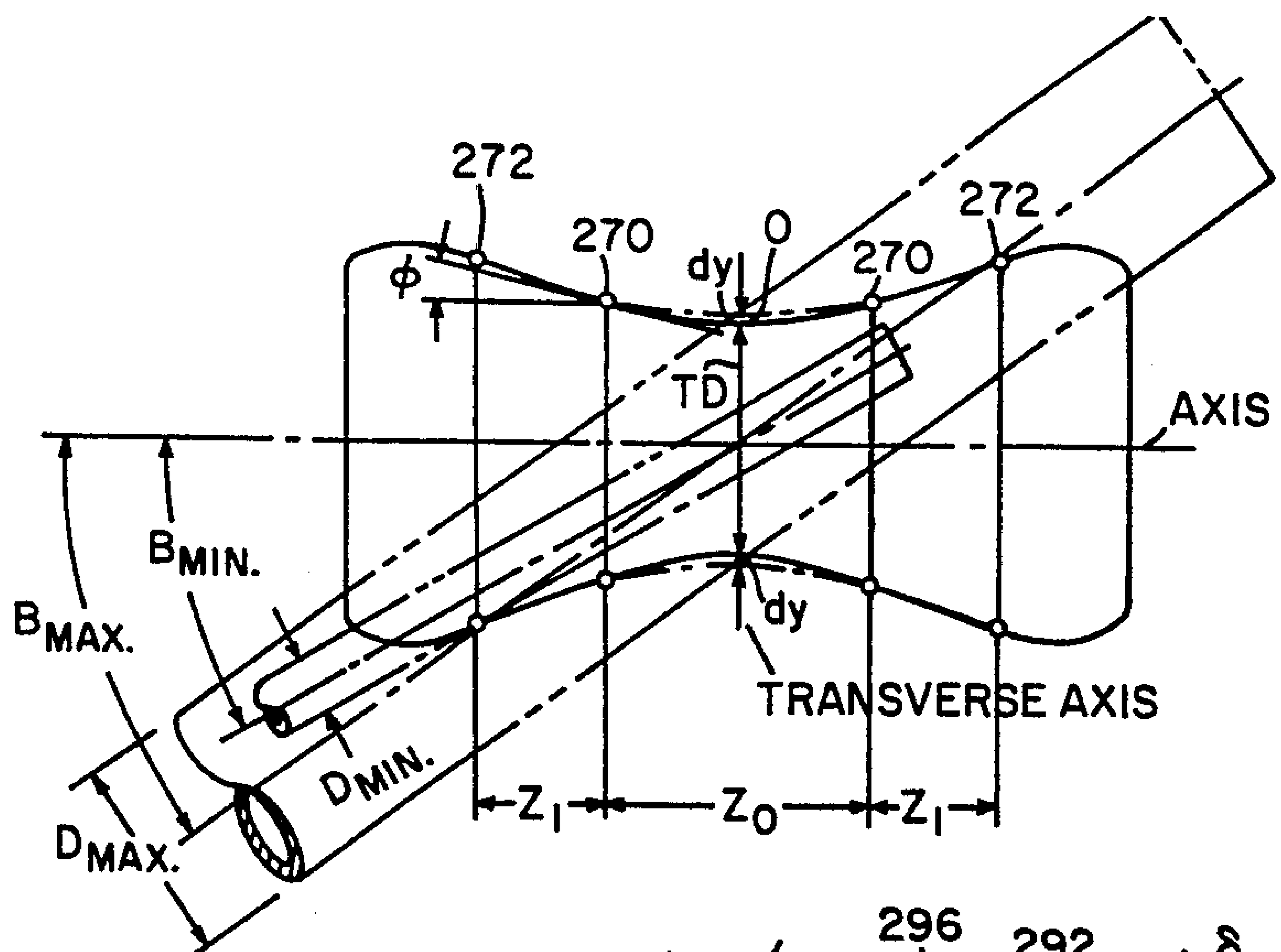

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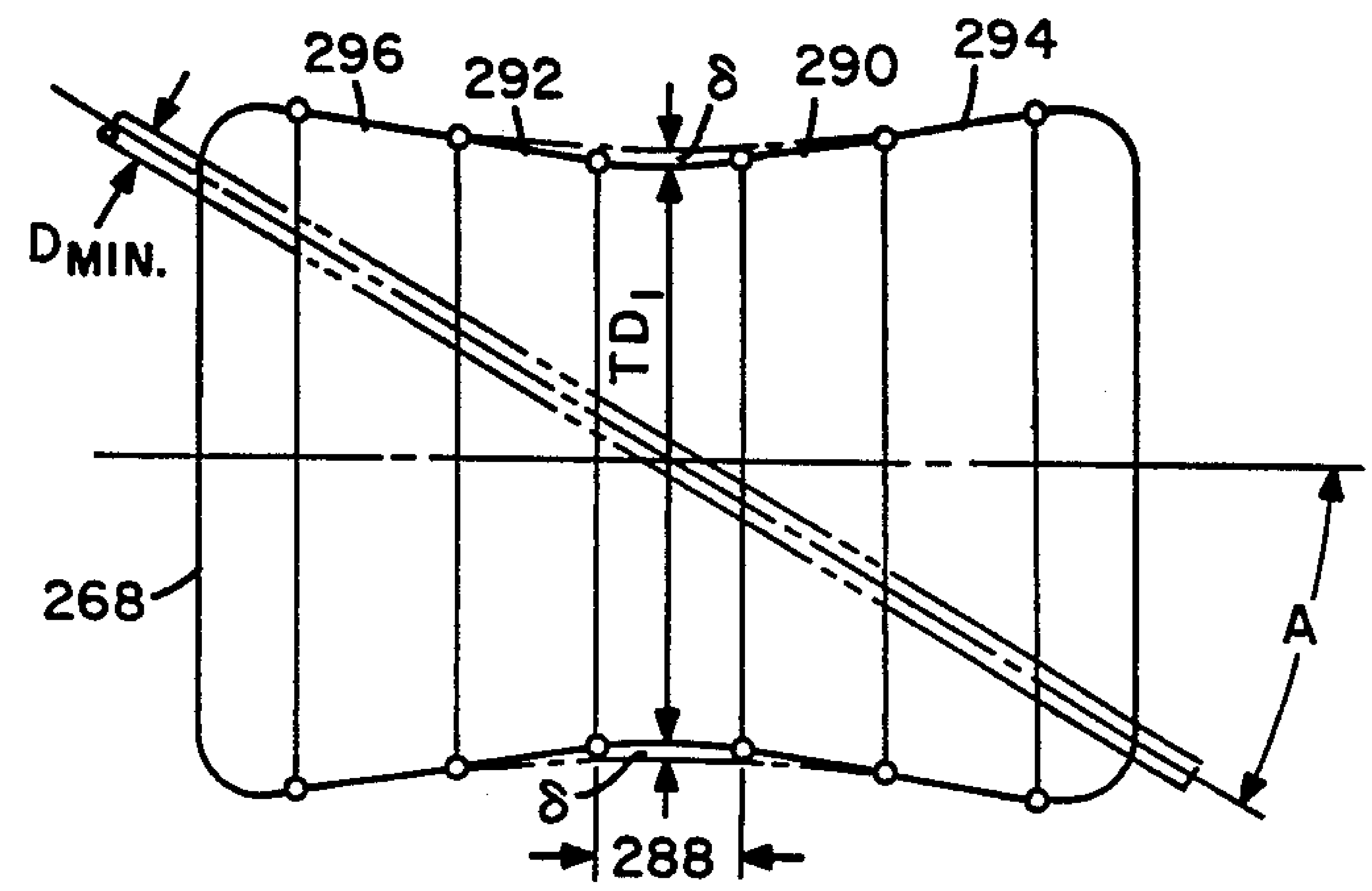

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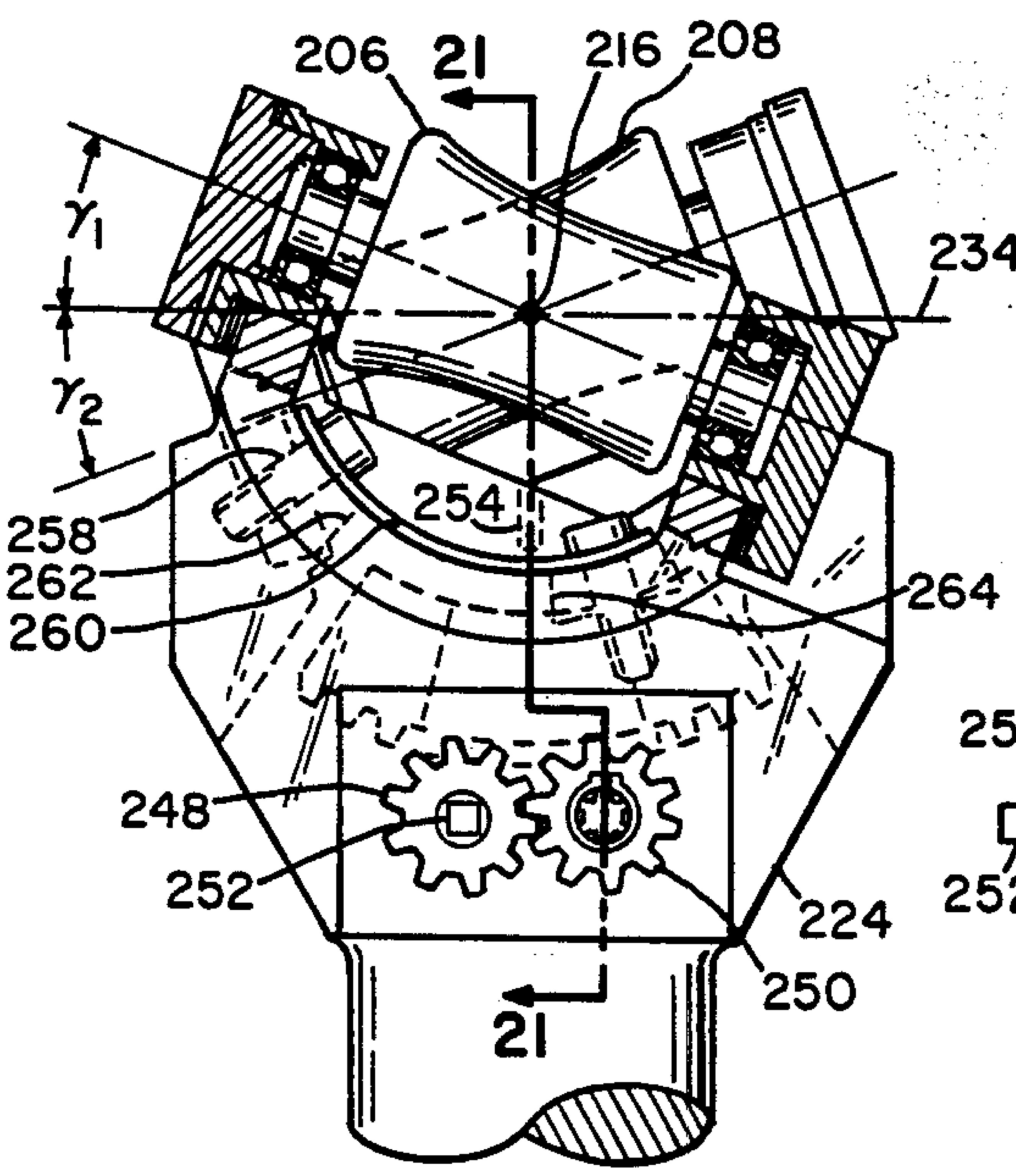

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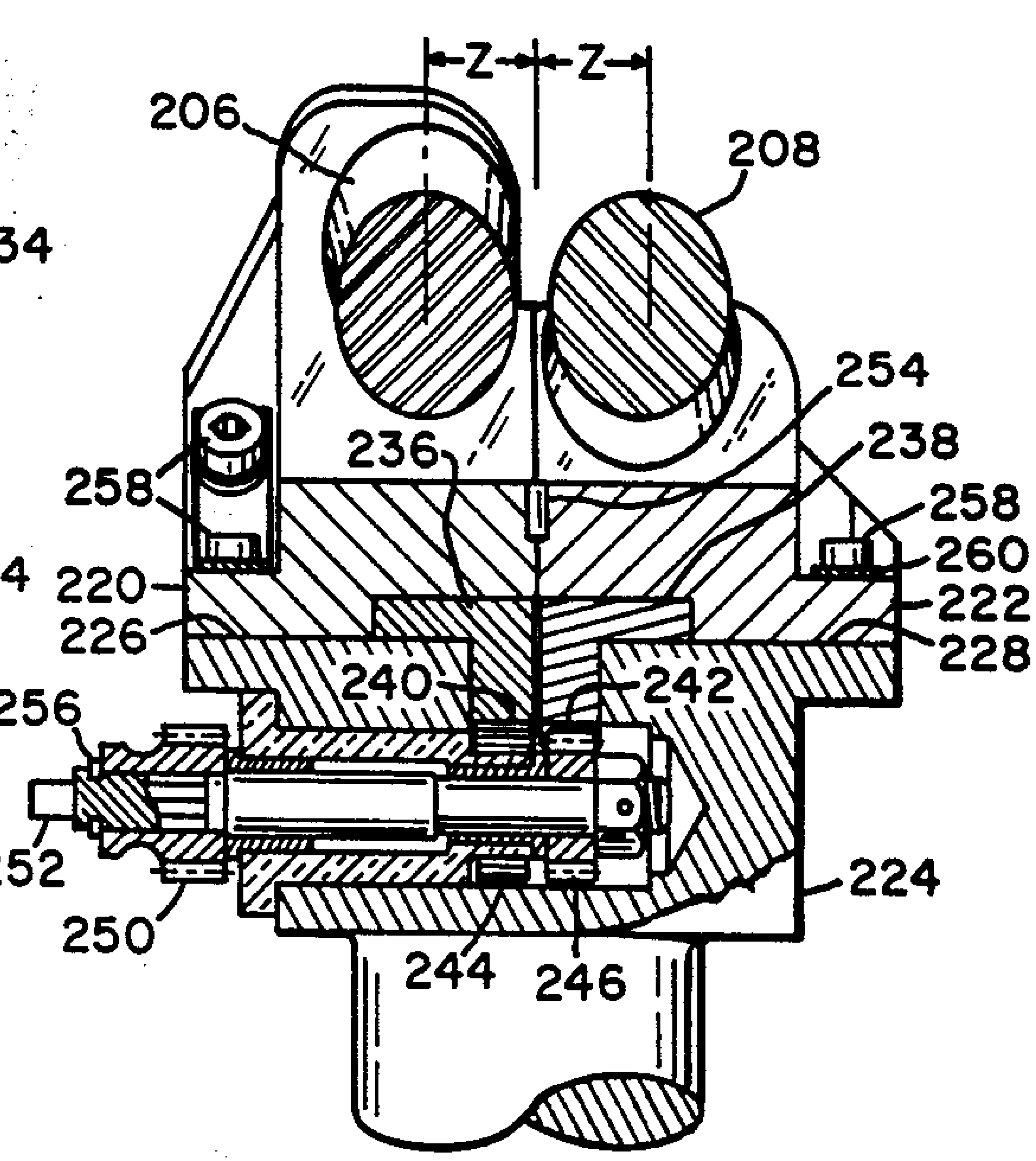

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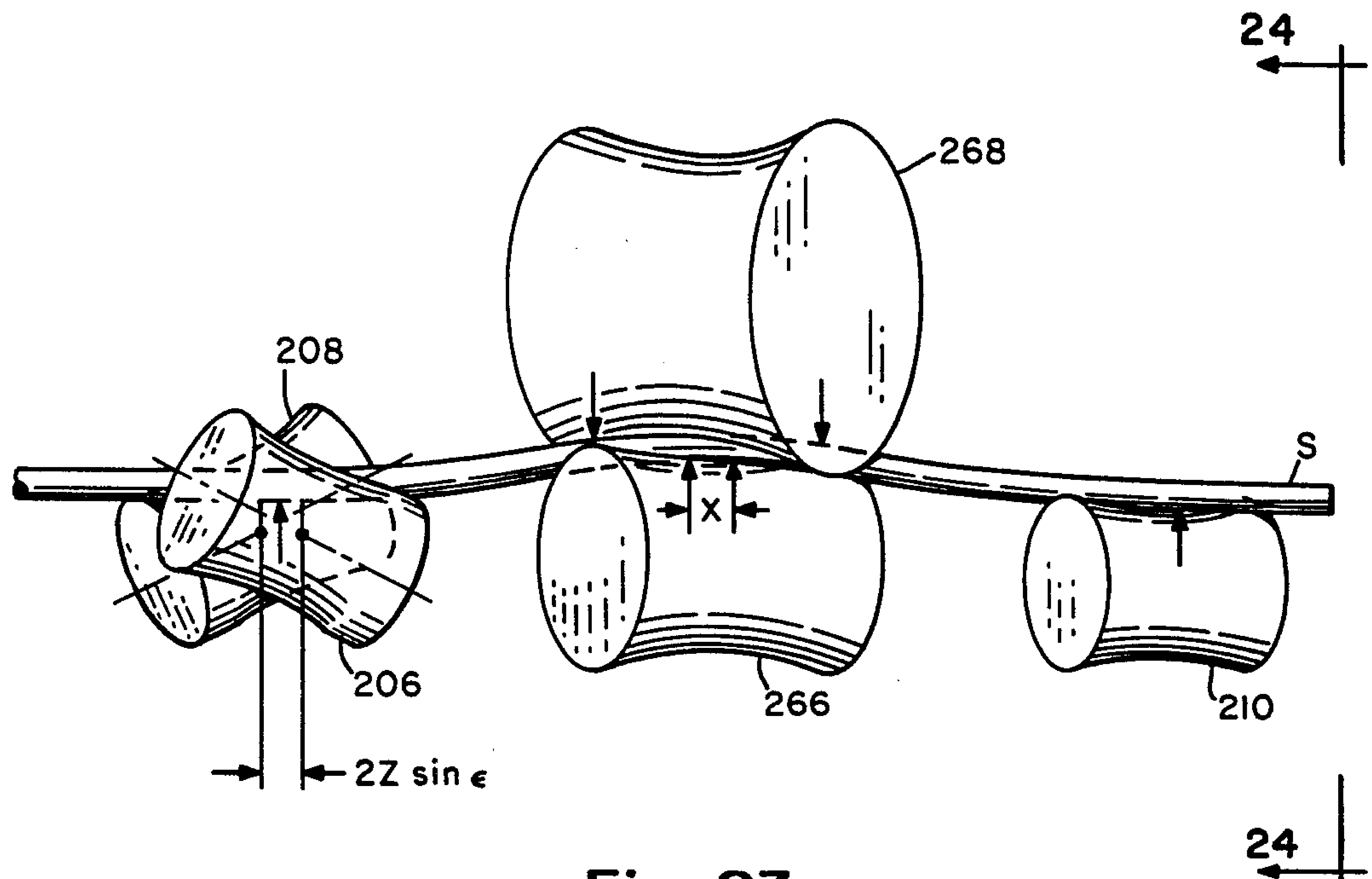

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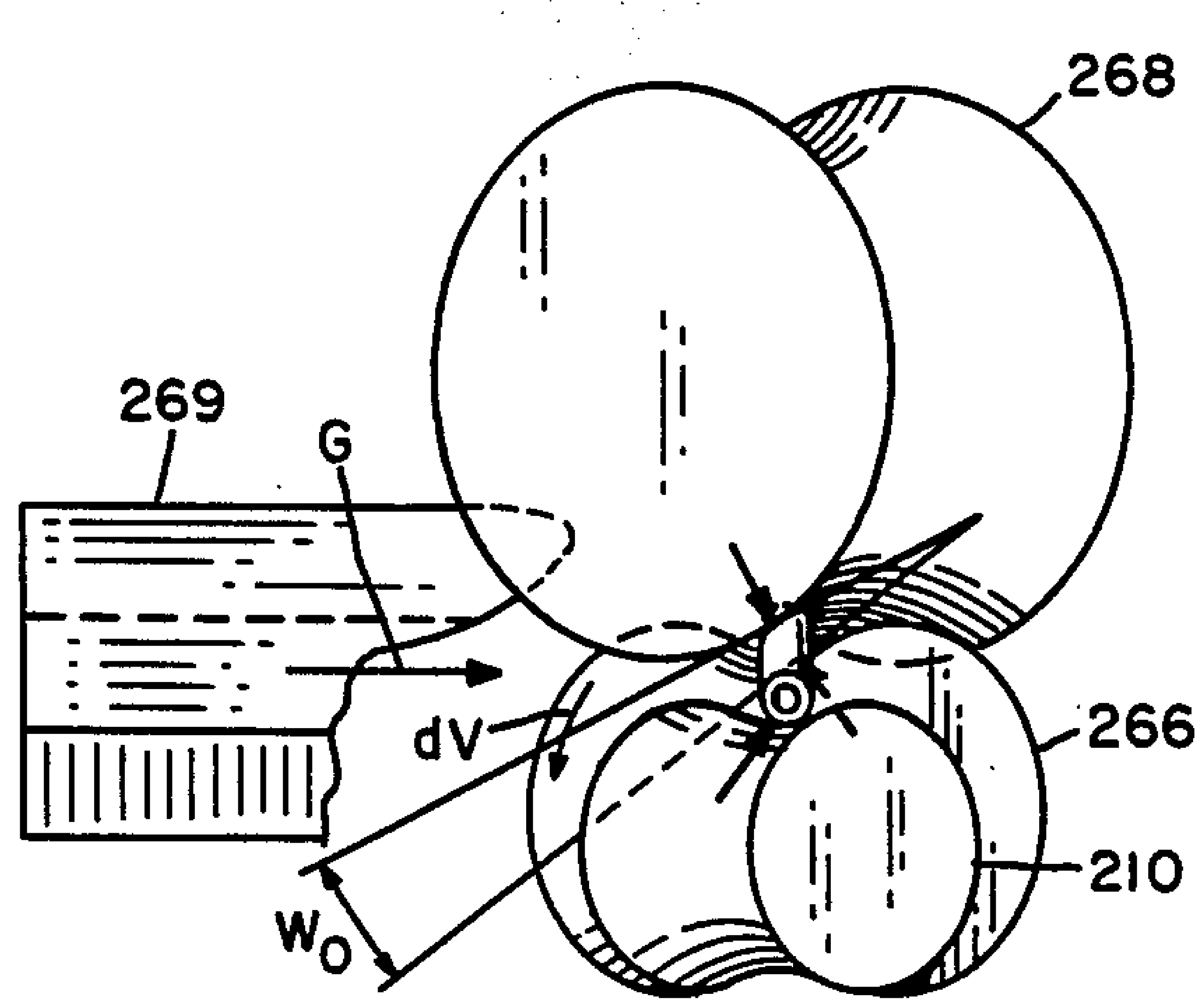

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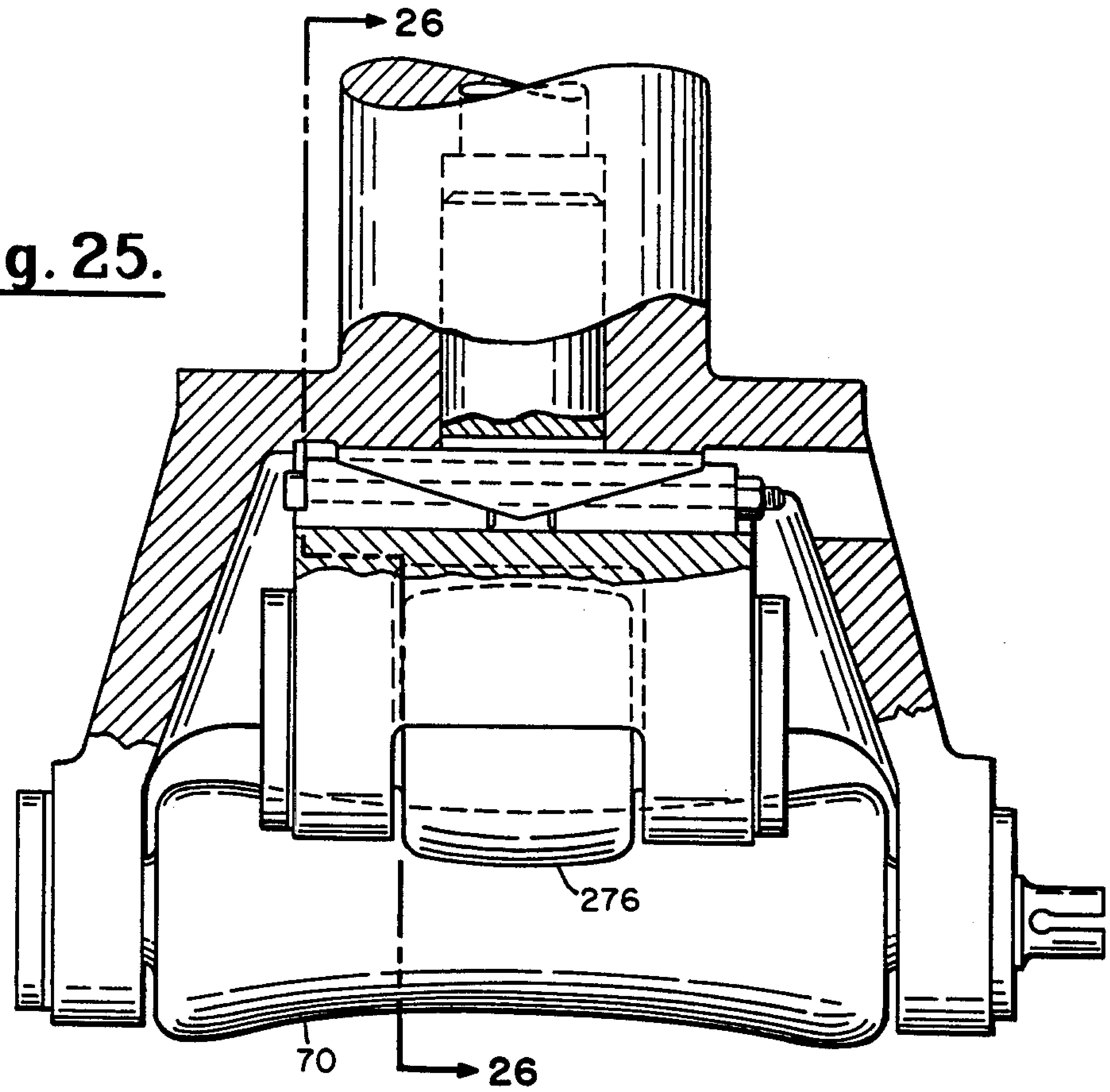

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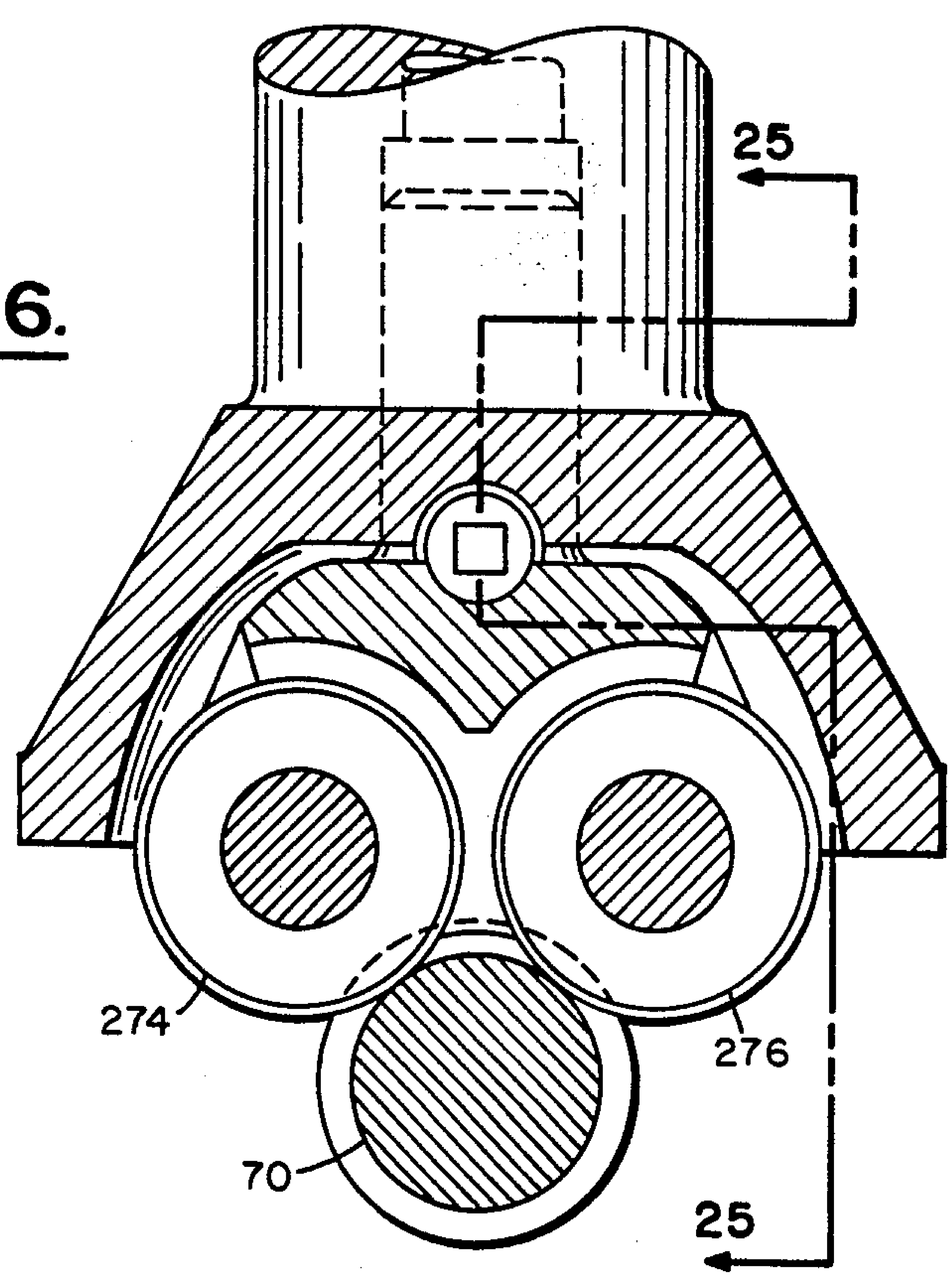

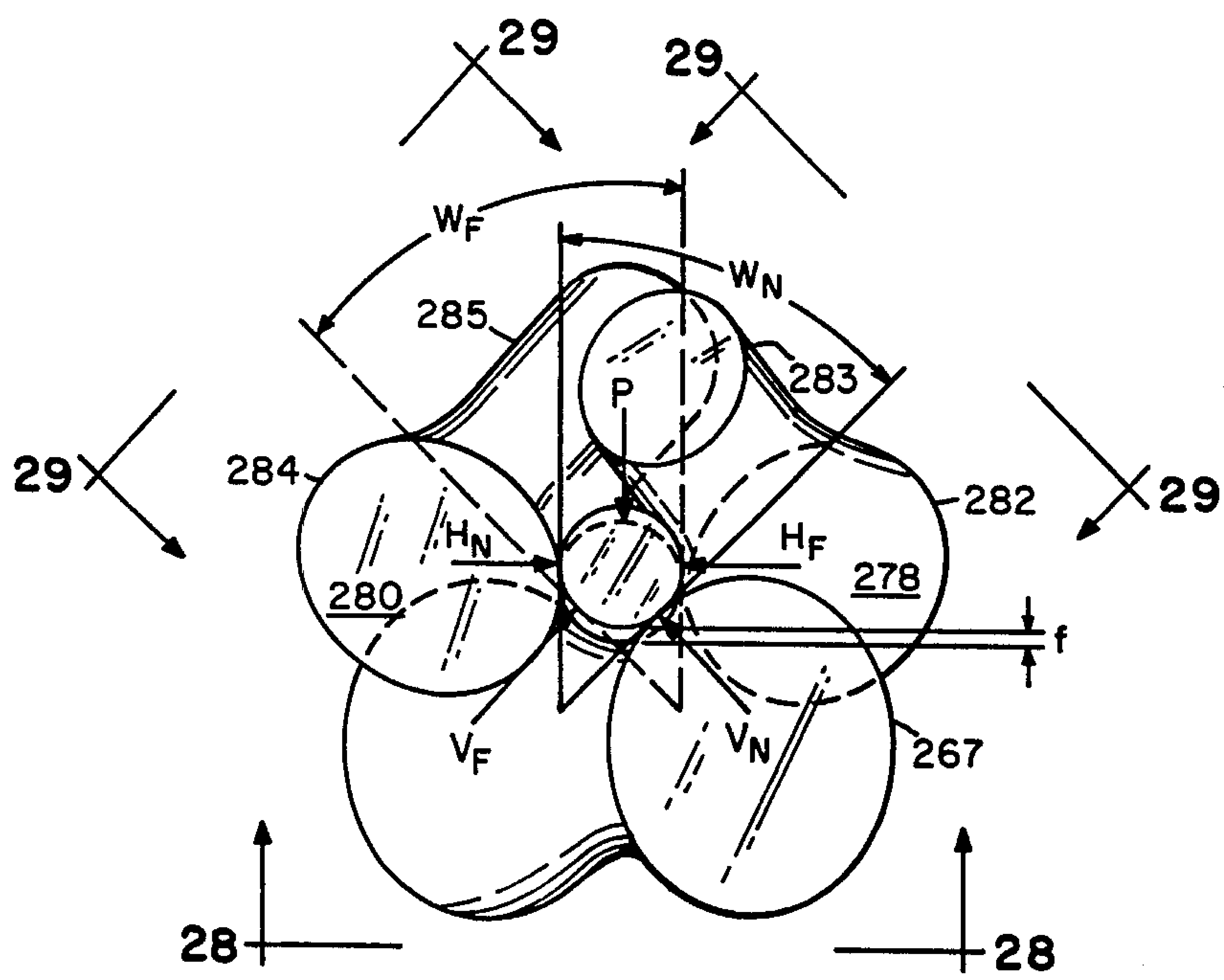

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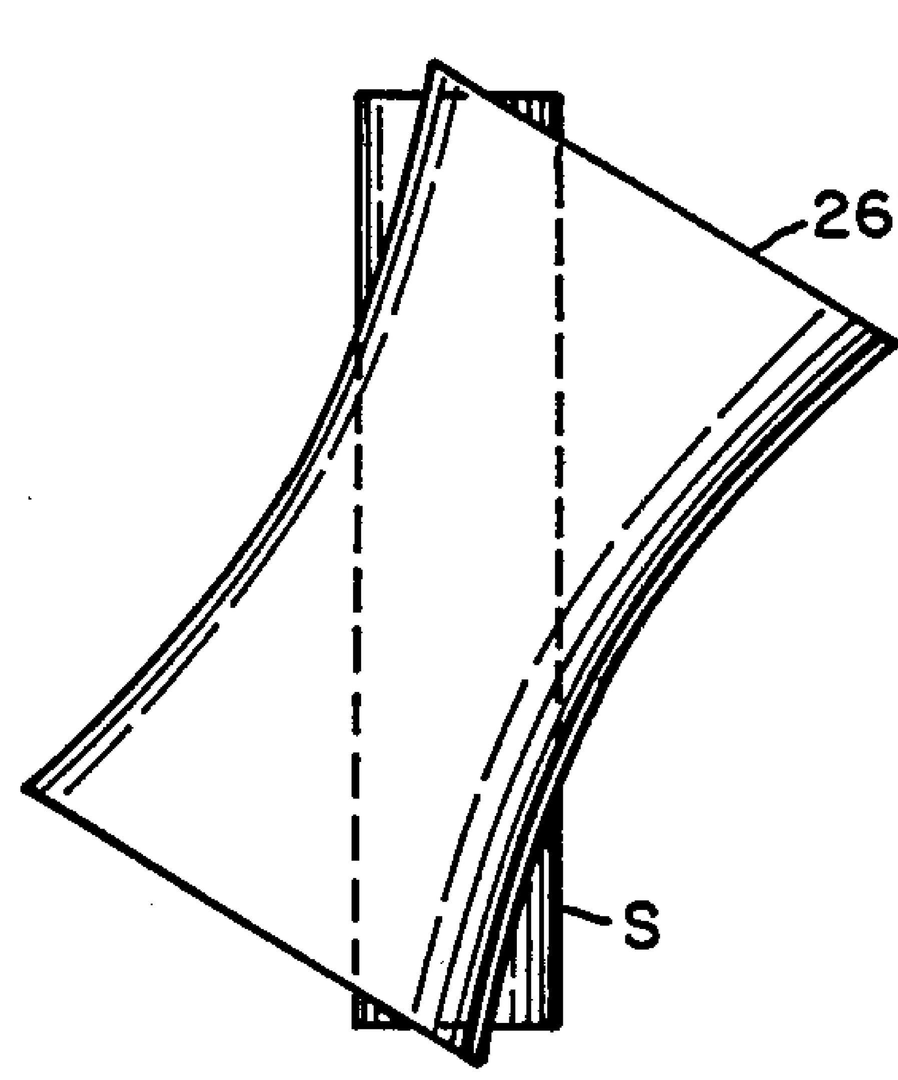

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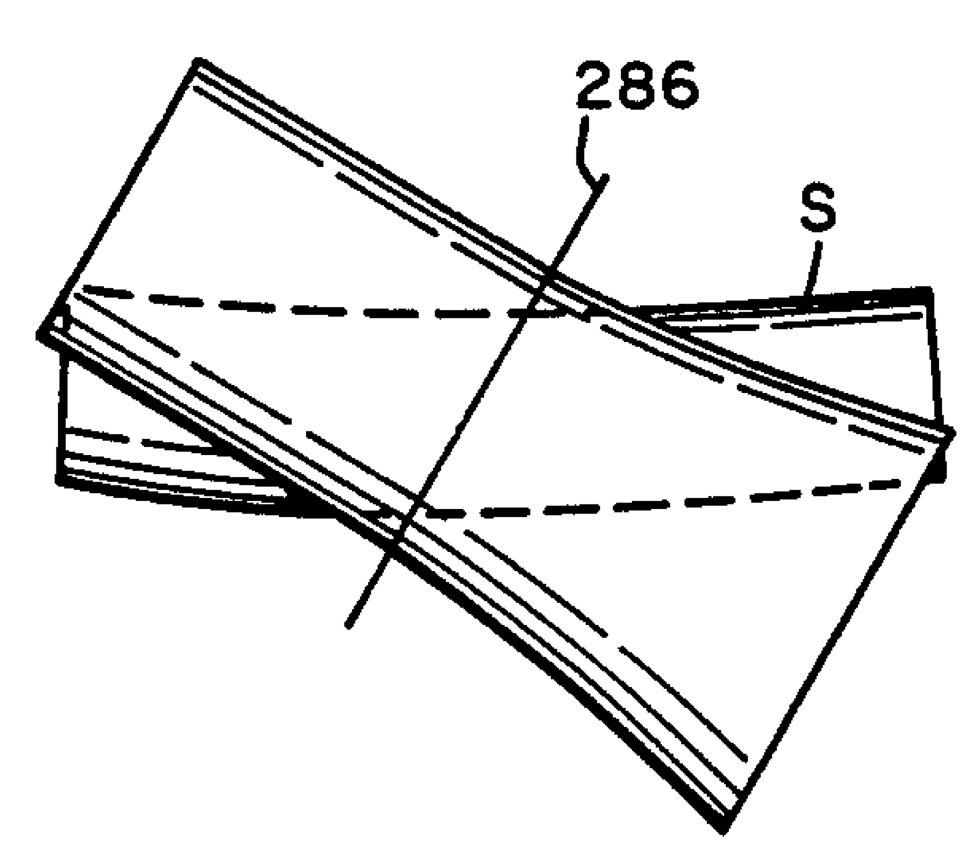

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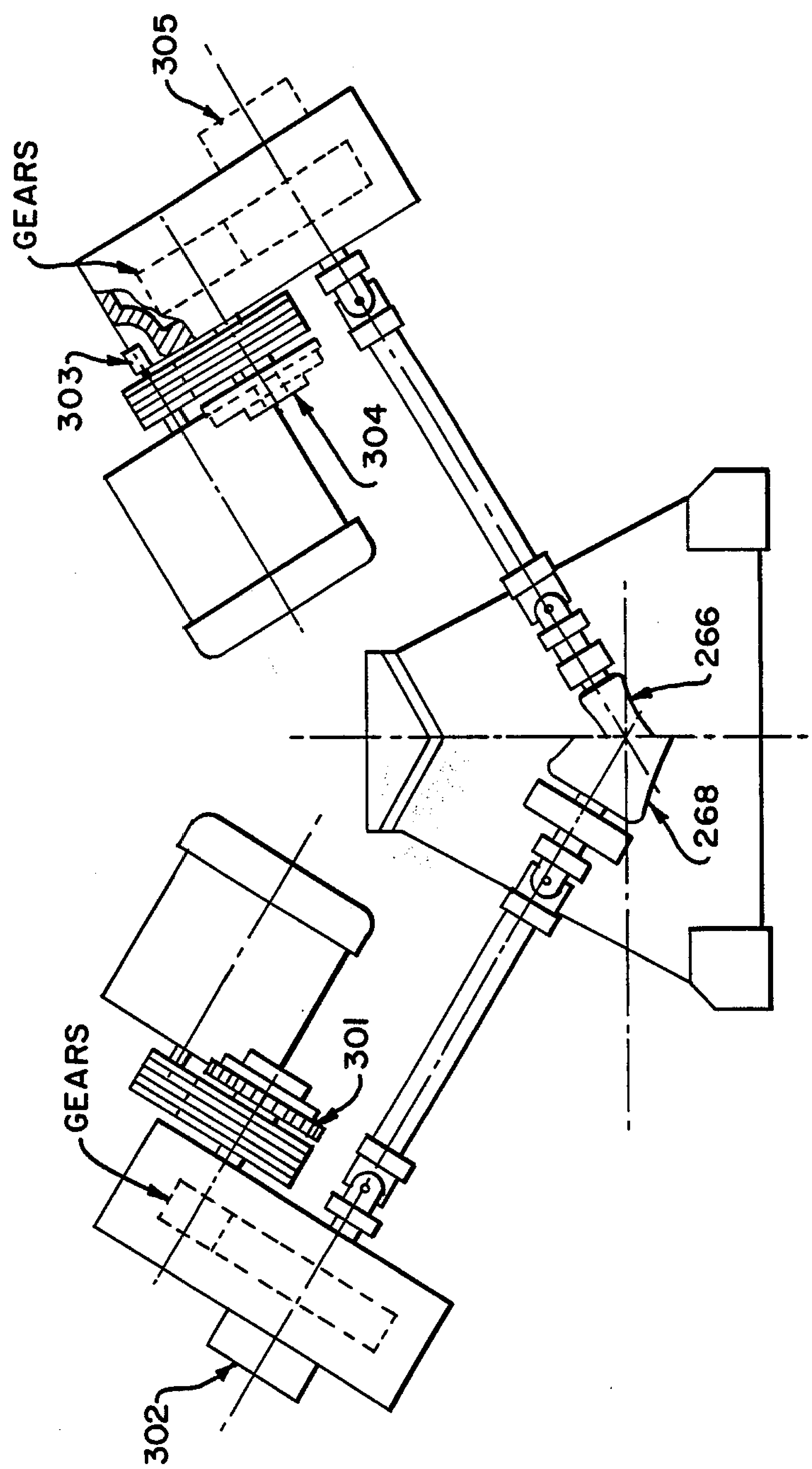

Figure 31

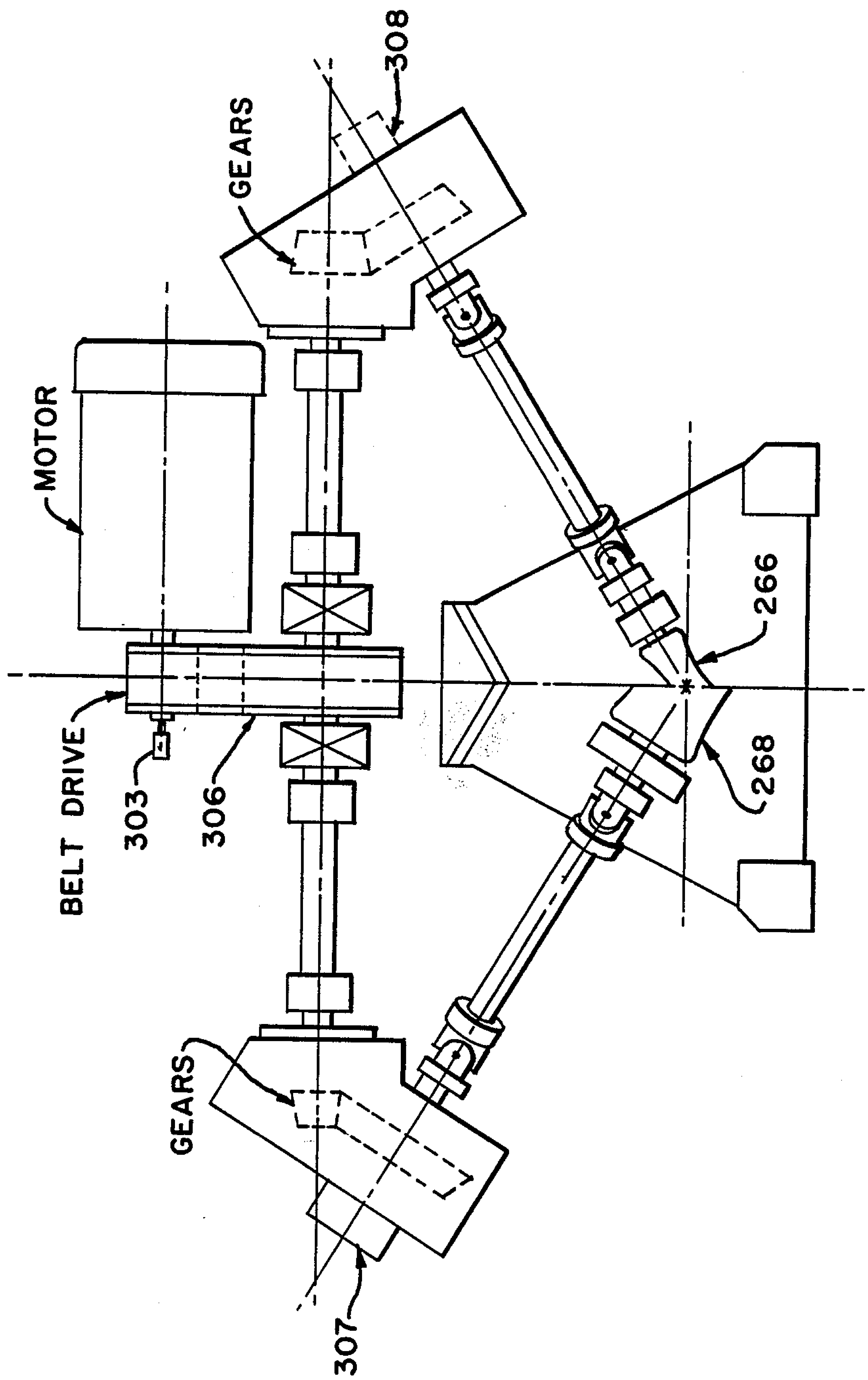

Figure 32

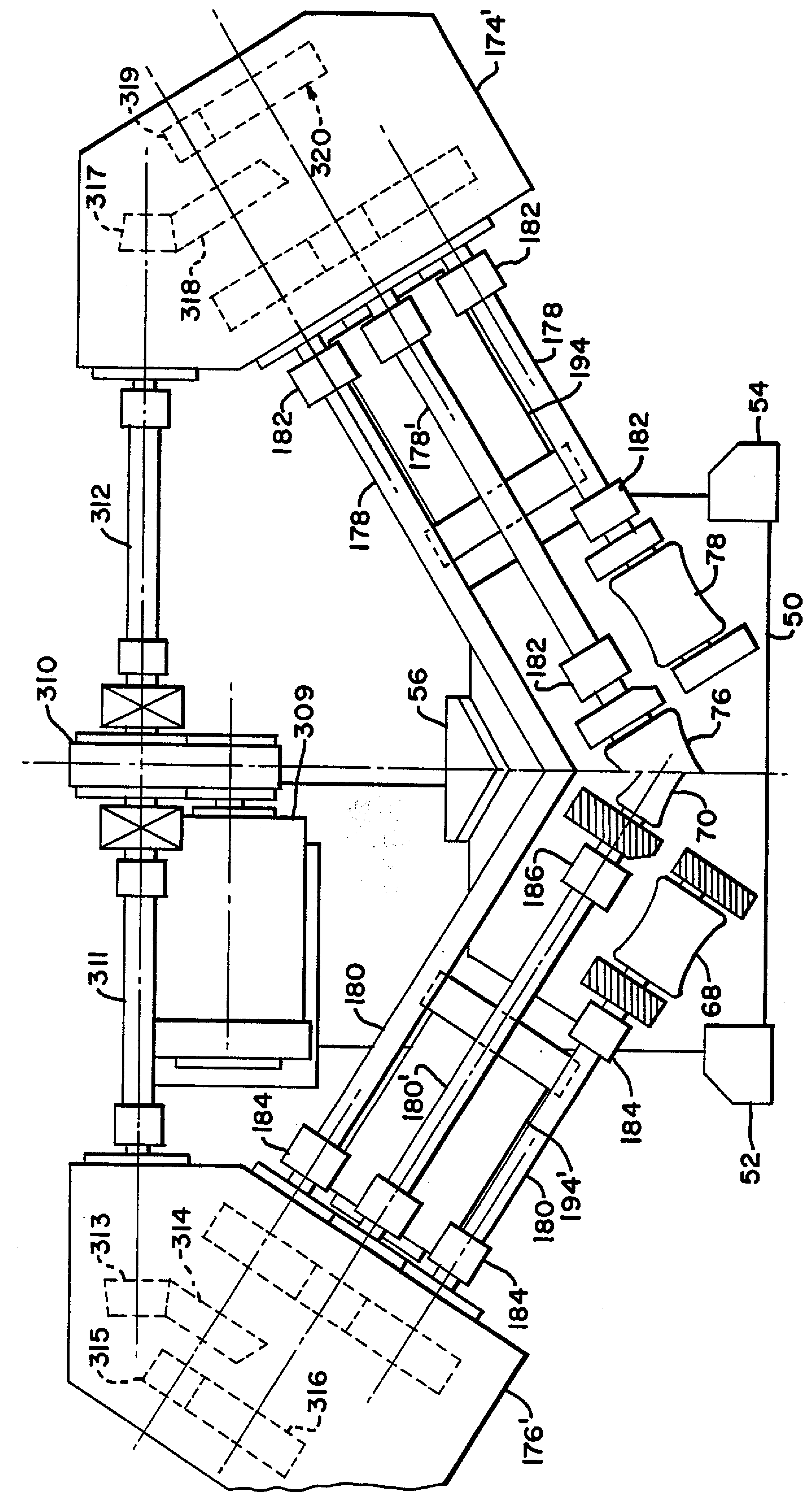
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Figure 33

STRAIGHTENING MACHINES AND METHODS

BACKGROUND OF THE INVENTION

RELATION TO OTHER APPLICATIONS

This application is a continuation-in-part of pending U.S. patent application Ser. No. 280,372, entitled "Straightening Machines and Methods", filed on July 6, 1981, now U.S. Pat. No. 4,494,394 granted Jan. 22, 1985.

FIELD OF INVENTION

The present invention is an improved cross-roll straightener that straightens round metal stock, wire, rods, bars, and tubes, by rotatingly advancing the stock through a curved pass such that it is flexed beyond the yield point in a substantially uniform manner. The invention also provides a method for maintaining the stock in the pass line of a cross-roll straightener.

DESCRIPTION OF THE PRIOR ART

Metal stock, such as wire, rods, bars and tubes, is formed by rolling, drawing and otherwise shaping the metal both while it is at elevated temperature and after it has cooled. The metal stock cools and cures in a heterogeneous manner such that a degree of warpage and curvature typically develops in the stock.

In the prior art, the stock has been straightened in machines known as cross-roll straighteners. Typically, such machines include one or more pairs of rolls that are disposed in skewed relation and spaced apart from each other. The space between the member rolls of each pair is called a "pass". Where more than one roll pair is used the roll pairs are adjacently arranged such that the "passes" of the roll pairs collectively define a "pass line" along which the stock travels through the cross-roll straightener. At least one of the rolls of each pair are rotatingly driven such that the stock is rotatingly advanced therebetween along the pass line.

In order to straighten the stock, conventional cross-roll straighteners generally apply a concentrated central load between supports to stress the stock beyond its yield point. Such concentrated central loads produce a peak bending moment that is applied in the shape of a helix on the surface of the stock as it rotatingly advances through the machine. Unfortunately, such a peak bending moment nonuniformly flexes the stock such that it is not evenly straightened.

Cross-roll straighteners of the prior art have many work roll arrangements that include various numbers of work rolls. For example, 2-roll straighteners of the prior art generally form a curved pass between a straight or convex roll and a roll having a concave contour. The straight or convex roll deforms the stock against the concave roll. However, such 2-roll straighteners require complex guides to maintain the stock in the roll pass, and have a limited capacity in straightening various sizes and materials.

An improvement in 2-roll straighteners is described in U.S. Pat. No. 3,047,046 in which a concave male roll is located on the convex side of the curved pass and is smaller in diameter than the female roll. Both rolls are contoured so that the stock is wedged between the rolls at the ends of the pass and thereby maintained in the curved pass without guides. The central portion of the curved pass in the straighteners of U.S. Pat. No. 3,047,046 has a substantially parabolic curvature such that the bending moment on the stock is substantially that of a uniformly loaded beam. However, because both rolls were concave and were contoured to contact the stock throughout the curved pass, a relatively large roll angle change for the female roll was required whenever a different diameter stock was straightened. Specifically the roll angle adjustment for the female roll is much greater than the corresponding adjustment for the male roll. Consequently, excessive slippage between the two rolls and the stock occurred for certain stock sizes and materials where the opposed roll had substantially different contact angles with the stock.

In cross-roll straighteners having more than two work rolls, the rolls are generally arranged in a plurality of cross-roll pairs, each forming a straight pass. The cross-roll pairs are arranged in laterally offset fashion so as to flex the stock as it advances along the pass line. Such arrangements have generally been found to be faster and more efficient than 2-roll straighteners. Typical examples are 5-roll and 6-roll straighteners. Conventional 5-roll straighteners have two pairs of cross-rolls and an intermediate single bending roll. Such 5-roll straighteners generally provide greater leverage for bending the stock than a single curved pass 2-roll straightener. However, 5-roll straighteners also require additional guides to maintain the stock in proper position as it passes through the machine.

Conventional 6-roll straighteners have three pairs of cross-rolls of equal diameter that form straight passes. The pass line is defined by a central pass that is laterally offset from the line between the end passes. As the stock moves along the pass, it is flexed between the central roll pair and supported by the two end roll pairs in a manner similar to a simple beam having a single load between two supports. 6-roll straighteners can generally be operated at higher speeds and without guides. 6-roll straighteners have generally been used for straightening tubular stock of small diameter and medium to low strength material.

However, these straighteners have required a longer bending span than 5-roll straighteners and, therefore, cannot uniformly flex all stock sizes to a minimum radius of curvature as required to flex most of each section to or beyond the yield point of the material. Some restraining action on the stock occurs in the endroll passes, as evidenced by the smaller slope of stock deflection at the ends of such straighteners. However, this restraining action is insufficient to provide effective reverse bends for all portions of the stock, or to eliminate problems with the tables, particularly the outlet end table. Such moderate restraining action on the stock, together with the lack of guidance in the roll pairs, does not produce sufficient uniform flexure for good straightening and also limits the stock capacity of the machine and the throughput speed of the stock. Another problem has been that the passes in conventional 6-roll straighteners do not provide positive guidance for the stock.

Because of the longer bending span, non-uniform flexure, and poor guidance of the stock, prior multiple pair cross-roll straighteners were much less effective in straightening the stock than 2-roll straighteners. In particular, the female roll of the central roll pair had a symmetrical roll contour that did not conform to the surface of flexed stock. The concentrated bending loads also resulted in concentrated roll pressure on tubular stock that is sufficient to oval thin wall tubular sections.

Prior attempts have been made to achieve more uniform distribution of the straightening loads in cross-roll straighteners, particularly for applications involving larger diameter tubing having a relatively thin wall. The examples of such prior art, as shown in U.S. Pat. No. 2,376,401; 2,757,707; and 3,008,510, however, have a straight central roll pass that interferes with the curved, flexed stock.

In the prior art, rolls having various multisectional contours have been developed to improve the flexure of the stock and the machine capacity for straightening various stock sizes and materials. For example, U.S. Pat. No. 4,056,958 includes a roll having a twosection curvature defined by hyperboloids. However, since the contour is not symmetrical, these rolls cannot be used to flex and straighten a large variety of stock sizes and materials. U.S. Pat. No. 2,655,194 describes a roll having a contour with five sections wherein the outer sections are used for straight passes of the stock, the central section is defined by a cylinder of smaller diameter than the outer sections, and the intermediate sections are portions of circular cones. The central section is used to form a curved pass for straightening smaller stock sizes. The intermediate sections are selected so that the roll can be manufactured in a single set up with a specially contoured grinding wheel. The problem with such multi-sectional contoured female rolls has been that they do not provide a curved pass for a broad range of stock sizes and, particularly, for larger stock sizes. Furthermore, they generally do not provide a curved pass for smaller stock of high strength material. In the prior art, straightening stock in a curved pass has required different roll angle settings for the female roll and the male roll. The large difference in roll angle settings required to straighten small diameter or high strength stock as well as larger stock sizes in the same pair of rolls has greatly limited the capacity of conventional curved pass straighteners.

Other difficulties also existed with the prior art cross-roll straighteners. For example, in roll angling mechanisms such as shown in U.S. Pat. No. 3,604,236, the yoke tended to slip during the straightening operation so that the roll support would move axially after the angling screws were tightened. Other mechanisms tended to vary due to play in the adjustment screw threads or gears. In conventional 6-roll straighteners, angling of the rolls was somewhat cumbersome in that it required adjustment of twelve handwheels to angle and lock the rolls in position.

As another example, the roll brackets were expensive and difficult to maintain. In removing the rolls, bearing caps had to be removed and retainer screws loosened, thus exposing the bearings. In order to obtain accurate axial roll adjustment, bearing retainers had to be loosened and shims added or removed.

As still another example, the main frames of conventional straighteners such as shown in U.S. Pat. No. 3,540,251 and 3,604,236 absorb moments from lateral forces at the top or bottom of loosely fitted tie rods that are deflected by lateral forces and vibrations. The tie rods are weakest where the moment is greatest and the restraining moments in the upper plate and the base are excessive due to the short distance of restraint.

Accordingly, to provide higher operating speeds and improved straightening through uniform flexure, there was a need in the prior art for a straightener having the advantages of a curved pass 2-roll straightener but with greater straightening leverage and better guidance, such as found in 5 and 6-roll straighteners. In addition, there was a need for a female roll suitable for use in a curved pass, but having a concave contour that would avoid excessive slippage between the rolls and stock for a broad range of stock sizes and materials.

SUMMARY OF THE INVENTION

In accordance with the present invention, stock is flexed in a curved pass to a minimum radius of curvature at which the stock is stressed beyond the yield point while the straightening loads are distributed more uniformly throughout the length of the curved pass. As the stock advances in rotary motion, it is positively guided in the curved pass and flexed to a minimum radius of curvature for at least one pitch of its surface, helical motion such that the stock is stressed in a substantially uniform manner.

Preferably, the female roll forming one side of the curved pass includes a central portion having an abrupt concave curvature and end portions that have a less abrupt curvature. The end portions of the roll are for straightening larger sizes of stock, and the central portion for straightening, by more abrupt flexure, smaller stock sizes or stronger materials. Thus considerably less variation is required in the female roll angles.

Preferably, the straightener includes three sets of cross-rolls with the central set laterally offset with respect to the other sets to increase or decrease the flexure of the stock as required while it is advanced in rotary motion by said rolls. Preferably, the rolls of the central roll pair are of unequal roll diameters to provide positive guidance of the stock. The rolls maintain the stock in the curved pass during the straightening operation and provide better guidance for both the leading and trailing ends of the stock as it enters and leaves the central pass. The central roll pair forms a curved pass that guides and complements the stock's flexure rather than merely applying a central load as in the prior art. Preferably, the flexure of the stock can be further improved by providing reverse flexures of the stock outside the curved pass as, for example, by outward adjustment or offset of the smaller, lower outer work rolls.

Preferably, concave cradle rolls are provided at each end of the cross-roll straightener to continuously bend the small stock in sizes reverse flexures during its forward, rotary motion, thus providing greater leverage for straightening a larger range of stock sizes and materials. The inlet and outlet cradle rollers also position the stock in the pass line and substantially reduce whipping of stock that is crooked or has end hooks, thereby permitting substantially higher operating speeds. At the outlet end, the leading end of the stock may be deflected in a generally horizontal direction, to protect the trough and rolls of the outlet table. The curved pass cradle roller assembly is comprised of generally inversely symmetrical twin rolls that provide a bending yoke between 3-roll clusters or between two cross-roll passes. When used as a bending yoke, the cradle rolls have an unsymmetrial contour and are arranged in reverse symmetry about their common central axis such that only half of each roll contour contacts the stock under flexure. In another application, the twin-roll bending yoke can be combined with an opposed female roll to act as a single bending cluster. In this embodiment, the bending yoke is adjusted with respect to the female roll for stock size and flexure. In an alternative embodiment, the 3-roll cluster is used as a bending cluster in combination with two adjacent 3-roll clusters. The 3-roll bending cluster is adjusted vertically in relation to the adjacent 3-roll clusters to augment the flexure obtained by the central bending rolls toward the bottom rolls of the adjacent 3-roll clusters. The twin-roll bending yoke comprised of rolls modified according to the subject invention can replace the single conventional bending roll of a conventional 5-roll straightener to great advantage, providing better guidance and better control of the stock's flexure while maintaining its smaller bending span and shorter roll center distances.

The preferred roll brackets allow for angular adjustments of adjacent rolls spaced at relatively small center-distances by arranging supports for the rolls in reverse symmetry about each roll's axis in such a way that stronger sections of each bracket will absorb torque produced by its roll. Therefore, increased bearing capacity is provided for rolls spaced at given center-distance by providing more space for the bearings on near sides of adjacent bracket ends, than provided in prior roll brackets.

The roll bracket construction also admits to rapid axial adjustment of the rolls by accessable adjusting screws to correct for inaccurate bracket machining and to compensate for rolls that are machined or worn off center.

Also the upper roll adjusting screws, preferably, are compactly preloaded in their respective screw box by adjustment of a spring loaded screw. Thus, the roll support will not move after the angling screws are tightened and will not sag when the angling mechanism is released or operated. The lower, central adjusting screw and the lower end rolls and their yokes are provided with hydraulically supported seats.

Especially on large machines, the roll angling mechanisms used for angling and locking the rolls include hydraulic cylinders and a single handwheel nut which limits the angular movement in only one direction.

Preferably, the drive includes a gear box for one or more roll spindles in response to a variable speed motor. Also preferably, the drive mechanism includes a single variable speed motor for each roll drive, the motor being mounted on the same side of the gear box as the universal joint spindles. Alternatively, one variable speed can be provided for each gear box, one driving the upper end rolls and the other driving the lower end rolls. A third variable speed motor is provided that drives the central roll pair through a geared differential, haaving two output shafts that each drive one roll of the central roll pair.

Also the drive for the larger diameter roll in the 2-roll straightener, preferably, includes a clutch and a brake for temporarily reducing the surface velocity of the larger roll such that, after the stock has entered the pass, the surface velocity of the larger roll will be substantially equal to the surface speed of the smaller roll.

Other details, objects and advantages of the invention will become apparent as the following description of certain presently preferred embodiments and certain presently preferred methods of practicing the same proceeds.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings show certain presently preferred embodiments of the subject invention and illustrate presently preferred methods of practicing the same in which:

FIG. 1 is a plan view of a presently preferred embodiment of the subject invention in partial section, showing some of the bottom work rolls with their respective drive and showing, in phantom, some of the top work rolls and their drive.

FIG. 2 is an elevational view of the apparatus of FIG. 1, portions of which have been removed to better disclose the details of the invention.

FIGS. 3 and 4 show the bottom roll drive in FIG. 1 with the drive spindles removed in FIG. 3 and shown in phantom in FIG. 4.

FIGS. 5 and 6 show the roll angling mechanisms and support for the lower end rolls. In addition, FIG. 6 shows an end view of the main frame.

FIG. 7 is a sectional view taken along line 7—7 of FIG. 1 showing an adjustment mechanism for moving the roll bracket and roll axially.

FIG. 8 is a schematic of the roll arrangement of the subject invention wherein a pair of guide rolls at the entry end guide and support the stock into the first pass of the main working rolls, and a single guide roll and horizontal guide support the stock at the outlet end.

FIG. 9 illustrates how the stock if flexed in FIG. 8.

FIG. 10 is a moment diagram for the stock of FIGS. 8 and 9.

FIG. 11 illustrates the wedge angles at the entry and exit ends of the central roll pair, where the female roll is of generally smaller diameter than the opposed, male roll.

FIGS. 12 and 13 show an alternative embodiment of the roll arrangement of the subject invention wherein the bottom end rolls are of generally smaller diameter than the opposed top end rolls and are offset outwardly with respect thereto.

FIG. 14 is a moment diagram of the stock as flexed in FIG. 12 beyond the yield point of the material to a constant radius of curvature over distance "x".

FIG. 15 is an illustration showing how the roll wedge-angles adjacent the central and end roll passes guide the stock during its forward travel in rotary motion.

FIGS. 16 and 17 show an alternative guide and guide roll for use at the outlet or inlet end of the main working rolls.

FIGS. 18 and 19 show the guide roll pair of FIG. 8 supporting one stock size.

FIGS. 20 and 21 are sectional views showing the guide rolls of FIG. 1.

FIG. 22 shows a female roll, used in a curved pass for flexing and straightening round stock.

FIGS. 23 and 24 show a pair of working rolls of a 2-roll straightener in which the male roll is of generally smaller diameter than the opposed female roll, with inlet and outlet guide rolls of the present invention.

FIGS. 25 and 26 show a roll that is supported against deflection by adjustable back-up rolls.

FIGS. 27, 28 and 29 show a 3-roll cluster curved pass that includes one female roll and two opposed male rolls.

FIG. 30 shows an alternative female roll having five sections.

FIG. 31 shows a clutch and brake in the drive means for the large diameter roll.

FIG. 32 shows one motor and a geared differential used to drive both of the (central) rolls.

FIG. 33 shows one motor driving the central roll pair of a multi-roll straightener through a geared differential with two output shafts, the other rolls being driven by other means.

PREFERRED EMBODIMENT OF THE INVENTION

A preferred embodiment of the subject invention is shown in FIGS. 1-7. The cross-roll straightener therein disclosed has a main frame including a main base **50** with integral extensions **52, 54** and **56** that are machined at the top. The main frame also includes main top plate **58** with integral extensions **60, 62** and **64**, that are machined at the bottom to match main base extensions **52, 54** and **56**. Extensions **52, 54** and **56** are fastened to extensions **60, 62** and **64**. Preferably, one or more bolts are provided for fastening each extension **52–60, 54–62**, and **56–64** with at least one bolt in two of said extensions being body bound in order to accurately position the top plate on the main base and absorb the lateral forces or shear between the top plate and the main base. Alternatively, dowels or tongue and groove members may be used in place of body bound bolts and the joints can also be hinged.

The largest moments due to lateral forces and vibrations in the main frame occur at the solid connections of extensions **52–56** and **60–64** to the main base **50** and top plate **58** while the moment at the midpoint connections **52–60, 54–62** and **56–64** is substantially zero. Thus the moments produced by shear forces are absorbed by the solid and integrally connected extensions at their strongest section. The bolts securing the upper and lower extensions are relatively short and comprised of high strength material. The short length of the bolts helps reduce the elongation caused by the separating forces of the roll loads during the straightening operation. The body bound bolts withstand the shear forces transferred from the main top plate to the main base without slippage. Preferably, the bolts are preloaded.

As shown in hidden lines in FIGS. **2** and **5**, a central removable tie rod **66**, can also be included to reduce deflection in the main frame where especially severe separating forces and vibrations are anticipated, such as when straightening bars and heavy wall tubing of high strength materials. The presently disclosed main frame is more economical to assemble, and more precise and substantially stronger than conventional straightener frames, yet it facilitates rapid roll changes.

The cross-roll straightener of the preferred embodiment further includes upper work rolls **68, 70** and **72** and lower work rolls **74, 76** and **78** which are arranged in pairs **68–74, 70–76**, and **72–78**. The opposed rolls of each roll pair are skewed or oppositely inclined with respect to the pass line. The angular inclination of the axes of rolls **68** and **74** are the same as rolls **72** and **78** respectively. During the straightening operation, roll pairs **68–74, 70–76** and **72–78** are separated by a distance equivalent to the diameter of the stock or slightly less, and have angular contact with opposite sides of the stock so as to advance it in rotary motion while flexing it in a curved roll-pass formed by the offset central roll pair **70–76**.

Work rolls **68–78** are mounted in brackets **80**, which are fastened to plates **82** by bolts **84**. Plates **82** are integrally connected to yokes **86, 136**, or **146**. Brackets **80** are constructed so as to support the roll neck bearings in inverse symmetry about each roll's longitudinal axis. The straightening loads have a tendency to turn each bracket **80** in counterclockwise direction about its respective centerline **88**. Therefore, roll bracket **80** supports the roll neck bearings laterally at portion **90** as well as vertically in the area where the main straightening load is transferred to plate **82** of yoke **86**. The supporting portion **90** of bracket **80** is thus arranged to allow room for larger bearings and roll necks at adjacent ends **92** of the roll brackets as compared to conventional roll brackets on equivalent centers.

As more specifically shown in FIG. **7**, a mechanism is also provided for axially adjusting the roll to compensate for uneven roll wear or inaccurate machining. Through this mechanism, the roll is adjusted to the center line of its support as well as the center line of its opposed roll and the pass line. A key **94** guides bracket **80** such that the roll moves along its axis when adjusted. The rolls are adjusted by loosening screw **96** and turning hollow screw **98**, until the proper longitudinal position of bracket **80** has been reached, after which screw **96** is again tightened. In addition, screw **98** which is threaded in the lug of bracket **80**, can be extended to provide room for a locknut (not shown).

In addition to the angular adjustment of the rolls and their brackets, the upper rolls **68, 70** and **72** and their brackets **80** are vertically adjustable to accomodate stock of various diameters. Furthermore, the central roll pair **70–76** is vertically adjustable to deflect the stock to stress the outer portions of the stock beyond the yield point of the material over a distance equivalent to one pitch of the stock's surface motion as hereinafter further explained and illustrated in FIGS. **8–10**. Specifically, handwheel **100** operates through a worm and gear reducer **102** to control adjusting screw **104**. Adjusting screw **104** engages screw box **106** which is secured to stem **108**, thereby moving yoke **86** with its attached plate **82** and roll bracket **80** and roll **68** up or down, as desired. Adjusting screw **104** is clamped to main top plate **58** at shoulder **110** but is free to turn. Play between threads of screw **104** in screw box **106** is prevented by a smaller diameter screw such as ball screw **112** which is threaded in a small diameter screw box **114** that is fixed in screw **104** and has the same thread pitch. Nut **120** is locked onto the smaller threaded portion at the end of screw **112** which is prevented from turning with respect to retainer **118**. Ball screw **112** is preloaded by spring washers **116** of sufficient strength to urge retainer **118**, yoke **86** and screw box **106** toward the lower side of the threads in screw **104**. This arrangement prevents roll **68** from sagging when unloaded.

Lower rolls **74, 76** and **78** are provided with hydraulic overload devices to prevent damage to the rolls, bearings, or other parts by yielding when the applied load exceeds an adjustable maximum limit such as caused by out-of-round or oversize stock. The overload devices are hydraulically interconnected and provided with a master control valve for fast simultaneous release of all the lower rolls. The lower adjusting screw **122** for the bending roll **76** and its bracket **80** are supported by a hollow piston **124** that is maintained in normal position by fixed retainer **126** under hydraulic pressure at cavity **128**. Hollow piston **124** and an extension or hollow rod are sealed at seals **130** and **132**. Hollow piston **124** supports adjusting screw **122** at surface **134** which will yield together with piston **124** when applied roll pressure at roll **76** exceeds a predetermined maximum limit. An adjustable pressure regulator and guage (not shown) are set to establish a maximum pressure limit at cavity **128** to enable the operator to control the load at which the respective roll yields. Other details of the lower, central screwdown are similar to those for the upper screwdown previously described.

The roll yokes for the lower end rolls **74** and **78** are supported by relatively simple, inexpensive hydraulic cylinders. As shown in FIGS. **2**, **5** and **6**, rolls **74** and **78** and their roll brackets **80** and yokes **136** are supported by rods **138** of cylinder **140** mounted on main base **50**. The rod ends are threaded in holders **142** that are provided with thrust bearings **144** on which yokes **136** are free to turn. In FIG. **6** the rods **138** are shown at the upper ends of their stroke in cylinder **140**, from which they will yield when the roll loads on rolls **74** or **78** exceed the pressure for which the cylinders **140** have been set. The lower end-roll yokes may be set to yield at less load than the central bending roll, since they yield only when oversize stock is fed into the straightener and receive much less load from the straightening operation.

Alternatively, a separate automatically controlled, rapid hydraulic release of the roll pressure similar to that described for the central roll **76** can also be used for the upper roll **68** or lower roll **74** the entering roll pair **68–74**. This will allow the stock to be entered sideways between the rolls of roll pair **68–74** when the upper roll is retracted, thus facilitating quick startup of the straightening operation. In such a case the extensions **52** and **60** must be relocated. If an upper roll screwdown is furnished with the rapid release mechanism described for the central, lower adjusting screw, the screw preload mechanism, including screw **112**, can be maintained.

The mechanisms for angling the yokes that support the end rolls and the middle rolls are substantially similar. Central yoke **146** shown in FIGS. **2** and **5** has two keyways **148** and **150** with which rounded key portions of spindles **152** and **154** slidingly engage. To decrease the roll angle of roll **76**, cylinder **156** is activated to turn yoke **146** in a clockwise direction. When roll **76** is in the selected angular position, cylinder **156** is stopped and the piston is locked by tightening nut and handwheel **158** and pressure in cylinder **156** is reversed. To turn adjusting screw **122**, pressure in cylinder **156** is temporarily released. In smaller machines, cylinder **156** can be substituted by another nut and handwheel similar to **158**. Similarly, the end roll yokes **136** each have two keyways with which rounded key portions **160** and **162** of spindles **164** and **166** slidingly engage, cylinders **168** are activated to turn yokes **136** in the direction desired. When rolls **74** and **78** are in the selected angular position, cylinder **168** is stopped and the piston is locked by tightening nut and handwheels **170** and **172** and the pressure in cylinder **168** is opened to the piston side. Spindles such as **152**, **154**, **164** and **166** are prevented from turning by keys and keyways (not shown). The threaded portions of the spindles having threaded handwheels, such as **158**, **170** an **172**, may be extended through the handwheels and provided with locknuts, beyond the handwheels (not shown) in order to secure their adjusted positions when the pressure in angling cylinders **156** and **168** is temporarily released for screwdown adjustments, for overload yield of the lower roll or for rapid release of the lower rolls. In such cases the relief of the pressure in the angling cylinders **156** and **168** should be automatic. For example, it could be activated by the movement of a lower roll and its support, as well as other methods and sensing devices known in the art.

The angling mechanisms for the upper roll supports are similar to those shown for the lower roll supports. The previously described preloading mechanism for the upper screwdowns advantageously prevents sag in the roll supports during the angling adjustment as well as when the screwdowns are operated.

The central adjusting screw **122** and the angular adjustment of the central lower roll **76** is operable regardless of the hydraulic pressure under supporting piston **124**. The angular adjustment of the lower end-rolls **74** and **78** and their yokes **136** is only slightly affected by the weight on their supporting cylinder rods **138** and the friction in the thrust bearing **144** supporting the roll yokes **136** on the rod ends.

In the preferred embodiment, the 6-roll straightener of the invention has two central rolls of generally unequal diameter while the end roll pairs have substantially the same diameters. Female roll **70** of the central roll pair is of generally smaller diameter than bending roll **76**. Concave rolls **68** and **72** are on the same side of the stock as female roll **70**, but of generally larger diameter than female roll **70**. Rolls **68** and **72** are opposed by concave rolls **74** and **78** that are generally the same size and shape as rolls **68** and **72**. Guide rolls **206–208** and **210** produce reverse flexures in the stock so that, considering the flexed portion L_1 of the stock by itself, the major reacting shear forces Q occur outside of the central curved pass and act at the points of contraflexure "P.C.", in the sense and direction shown dotted in FIG. **9**.

Roll pairs **70–76**, **68–74** and **72–78** are driven by gear drives **174** and **176** that are connected to spindles **178** that drive rolls **74**, **76** and **78** and spindles **180** that drive rolls **68**, **70** and **72**. Spindles **178** and **180** are of uneven lengths. Spindles **180** and gear drive **176** are connected to upper rolls **68**, **70** and **72** through universal joints **184** and spindles **178** and gear drive **174** are connected to lower rolls **74**, **76** and **78** through universal joints **182**. The drive drive further includes a first common gearbox for spindles **178** and a second common gearbox for spindles **180**. Preferably, each gear drive is connected to three motors for individually driving spindles **178** and **180** with two of the motors located above the spindles and one below.

Preferably foot mounted motors are used with two motors mounted to upper plate **186** (shown in phantom) and the lower mounted to lower plate **188**, the motor shafts are connected to the pinion shafts by means of flexible couplings (not shown). The motors are all shown flange mounted in FIG. **4**. In high speed applications, it may also be preferable that the spindles are of equivalent lengths between the respective universal joints **182** and **184**. In such cases, the splined shafts that rest in the hollow splined output shafts of the gear drive can be extended and mounted in a floating bearing mounted on plate **186** for support.

Gear drive **174** is shown more particularly in FIGS. **3** and **4** wherein two upper motors **190** and **192** and one lower motor **194** drive pinions **196** and intermediate gears **198**. Gears **198** in turn drive the output gears **200** mounted on hollow splined shafts, which drive spindles **178** by means of universal joints **182**. Preferably gears **196**, **198** and **200** are all straight spur or helical gears mounted on parallel shafts, to provide an efficient and economical arrangement. According to the disclosed arrangement, the distances BB-BB in FIG. **3** can be increased in order to accommodate larger frame motors without increasing the distance between spindles **178**. Mounting motors **190**, **192** and **194** on the same side as the drive spindles advantageously provide a more compact arrangement. Preferably motors **190**, **192** and **194** are mounted on gear drive **174** or its bracket extension **186** or **188** and then, in field assembly, the drive means with its motors is mounted on bed plate **202** and main base **50**.

Top roll gear drive **176** is substantially the same as bottom roll gear drive **174** except that the gear reduction for driving the smaller top roll **70** is lower in order to develop substantially the same circumferential speed for roll **70** as for the other working rolls.

Because of the difference in shape and size of the central rolls **70–76** of the 6-roll straightener arrangements of FIGS. **8** and **12**, it is difficult to establish their ideal speed relationship. However, as shown in FIG. **33**, by providing a variable speed motor **309** driving a differential **310** with two output shafts **311** and **312**, one for each of the rolls **70–76**, the speed of the two mentioned output shafts, when geared in proportion to the roll diameters, will assume their ideal relative speed relationship as soon as the stock is entered in the pass between the central rolls. The variable speed motor can then be adjusted to equalize the speeds of the central roll pair in relation to the end roll pairs **68–74** and **72–78**. To provide such a differential to equalize the relative speeds of two opposed rolls is not new in the art. However, it is new to use one variable speed motor to equalize the speed of one roll pair **70–76** in relation to other roll pairs **68–74** and **72–78**.

The operation of the present invention is generally illustrated in FIGS. **8**, **9** and **10**. As shown in FIG. **8**, roll pairs **70–76**, **68–74** and **72–78** are inclined with respect to a longitudinal axis by roll angles A, B and C. The stock S is shown as moving in the direction of arrow **204** as it is rotated such that any point on the surface of stock S will move the pattern of a left hand helix. Roll pairs **68–74** and **72–78** have straight pass contours while roll pair **70–76** forms a curved pass for the stock. Roll **76** is the bending roll and is located on the convex side of the central curved pass. Roll **70** forms the concave side of the central curved pass. Roll angles A and B of the central rolls **70** and **76** are adjusted for flexure and size and roll angle C of the end rolls **68**, **72**, **74** and **78** are varied or adjusted to suit the various sizes of stock. The end roll pairs **68–74** and **72–78** and central roll **70** are adjusted to lower roll-angles B and C for smaller sizes of stock S. Because roll **76** is on the convex side of the curved pass, generally smaller changes in roll angle A are reguired to accommodate variations in stock sizes than are required for roll **70**. In order to maintain a substantially constant speed ratio between rolls **70** and **76** for the outside and inside curvatures of the stock as it moves forward in rotary motion, it is important that variations in the roll angle B of roll **70** to accommodate changes in stock sizes be small in relation to roll angle A. Roll angle B is thereby kept substantially equal to roll angles A and C for the full range of sizes and materials for which the straightener is intended to be used.

As illustrated in FIGS. **8**, **9**, **10** and **11**, the central roll pair **70–76** of the present invention is designed to flex the stock to a desired minimum radius of curvature over a distance x equivalent to at least one pitch of the helical travel of the stock surface. The central roll pair thereby flexes all portions of the stock to a substantially uniform radius of curvature in all directions for improved straightening by flexure. This flexure results in approximate loads B, A, C and D as illustrated in FIG. **9**. In addition, as illustrated in FIG. **10**, substantially constant moment MY is provided over distance x.

Since the average diameter of roll **70** is smaller than the average diameter of roll **76**, particularly the diameters at the roll ends the preferred embodiment provides substantial support in the wedge angles as well as close guidance of the stock. As shown in FIG. **11**, an appropriate ratio between the opposed rolls **70** and **76** is selected with respect to the stock's flexure to form stock contact angles W_2 and W_3 at the respective ends of the central pass. The rolls thus support the stock within angles W_2 and W_3 at the ends of the intermediate roll pair to provide support throughout the curved pass. As illustrated by Shear Q, FIG. **11** further shows how the flexure of the stock S forces it into the angles W_2 and W_3 at both ends of the central curved pass. FIG. **11** is taken along line **11—11** at the entry end of the central roll pair, but would be the same if taken in the opposite direction at the outlet end of the central roll pair. This is completely contrary to the roll diameter proportions as known in the prior art where the bending roll is smaller than the female roll and where the main bending forces are contained within the curved pass.

An alternative embodiment of the cross-roll straightener of the subject invention is illustrated in FIGS. **12–15** wherein stock "S" is shown in exaggerated flexure. The embodiment illustrated in FIG. **12** has a central curved pass that is formed by the male bending roll **76** and female roll **70** of generally smaller diameter opposed thereto. For the alternative roll arrangement of FIGS. **12–15**, rolls **74** and **78** are of generally smaller diameter than rolls **68** and **72** and are offset from rolls **68** and **72** by an adjustable distance "e" along the longitudinal axis of the machine and outwardly from the center thereof. This adjustment is not required for the embodiment of FIGS. **1–8**. As shown in FIG. **15**, the adjustable offset "e" of rolls **74** and **78** restrains the stock in the end passes by forming wedge angles W_1 and W_4 adjacent the inside ends of roll pairs **68–74** and **72–78**. Wedge angles W_1 and W_4 complement the wedge angles W_2 and W_3 adjacent to the ends of the central pass. The magnitude of offset "e" is thus selected to substantially reduce lateral movement of the stock adjacent the inside ends of roll pairs **68–74** and **72–78**; to improve reverse flexure of the stock; and the entry and delivery of the stock.

In some cases, particularly where the female roll is small in diameter with respect to the male roll, the diameter of the female roll at the contour end can be very large in proportion to the diameter of the female roll at the transverse axis.

In such cases, it may be preferable when straightening large size stock that the stock does not touch the central portion of the contour of female roll **70** to avoid excessive "slippage" between the stock and the female roll through the central contour. Thus, the compound contour of the female roll will allow for a gap "t" as shown in FIG. **12** to be maintained between the stock and the female roll **70**. On the other hand, by increasing all roll angles slightly and applying roll pressure on the stock at the transverse axis of the central roll pair, the female roll ends will not touch the stock, while the central "cold work" will augment the flexural stresses for more efficient straightening, particularly when the stock is tubing.

Still another 6-roll arrangment may seem better for straightening end hooks. Such an arrangement will have a central straight pass roll pair wherein the smaller diameter roll and a portion of the larger diameter roll are adjusted above the roll pass of the entering and leaving end roll pairs. Compare FIGS. **8**, **9**, and **12**. The stock's leading end will enter the central pass without difficulty and be guided by the wedge angle at the entering end of the central pass. Almost any amount of flexures may be obtained between the roll pairs. Only peak moments are obtainable, however, and a near constant moment over distance "X", shown in FIGS. 10 and 14, as required for good straightening, is unobtainable.

Another 6-roll arrangment having a central curved pass roll pair of uneven diameter rolls, where the female roll is the larger diameter roll, will require speed control of the central rolls in order to enter the leading end of the stock into the central pass, if the central curved pass is to augment the main flexure between the end roll pairs.

Still another roll arrangment, similar to the 6-roll arrangement of FIG. 8 should be mentioned. In this arrangment the end roll pairs are substituted by 3-roll clusters and the axis of the small diameter female roll is parallel to the axis of one roll in each 3-roll end cluster. By having such a roll arrangement it is possible to drive the three rolls in a cluster roll straightener with 50% more driving power than for a conventional 7-roll straighteners. In addition, the central female roll will guide the stock into the wedge angle at the entry end of the central pass and start the opposed male idler roll rotating by frictional engagement between the stock and the two rolls. Such an additional female roll will greatly increase the capacity of the machine to straighten the smaller diameter, high yield strength tubes. It will also straighten upset end tubing better, since the female roll may be temporarily withdrawn, automatically, as the upset end activates a sensing device near the entry end of the central roll pair, which actuates the hollow piston and withdraws the roll and its support, as already described for the central lower roll 76 in FIG. 2.

Twin Guide Rolls

In addition to the work roll pairs 70–76, 68–74 and 72–78, the subject invention can further include guide rolls at the inlet and outlet ends of the straightener. FIGS. 1 and 2 show a preferred embodiment having twin guide rolls 206 and 208 at the entering and exit ends of the 6-roll straightener. FIG. 8 illustrates the use of twin guide rolls 206 and 208 at the entering end in combination with a single guide roll 210 with a guide 212 at the exit end of the straightener. Single guide roll 210 and guide 212 are shown in detail in FIGS. 16 and 17. Twin guide rolls 206 and 208 and guide roll 210 in combination with guide 212 form straight passes. Guide rolls 206 and 208 are further provided with a vertical adjustment similar to that of roll 76 as may single guide roll 210. Used in combination with two horizontal guides 212 and 214, single guide roll 210 can be substituted for guide rolls 206 and 208 at the entering end of the 6-roll straightener. Such a combination is less expensive than twin guide rolls 206 and 208.

As shown in FIGS. 1, 2 and 8, guide rolls 206, 208 and 210 are not driven but act as cradles to position the stock at the entering and exit ends of the straightener and to maintain the ends of the stock in the pass line. These guide rolls provide supports that flex the stock into reverse flexures, to better straighten reverse bends and end hooks in the stock. The guide rolls also reduce whipping of the stock caused by the crookedness thereof to allow higher operating speeds for the straightener.

Preferably, the guide rolls are provided with flexible, shock absorbing supports that absorb the impact of the whipping action of the stock as it is rotatingly advanced through the straightener. If the guide rolls 206–208 and 210 are not touching the stock, the latter will assume a single flexure between roll pairs 68–74 and 72–78, similar to a simple beam on two supports A—A. See FIGS. 8 and 9. Such a single flexure and moment diagram will produce the relatively smallest straightening loads A—A and C—C caused by the approximate roll loads D—D, and is sufficient to straighten the larger stock sizes. For smaller stock sizes, however, more abrupt flexures are required and by adjusting the outboard guide rolls 206–208 and 210, vertically, so as to produce sufficient forces B that will subject the stock to reverse flexures; the single flexure will be reduced in length from the distance between the roll pairs 68–74 and 72–78 to the distance L, between the points of contraflexure P.C. as shown in FIGS. 9 and 10. In the latter case the straightening loads will be relatively larger, but for the small stock sizes the loads can still be held lower than those required to straighten the largest stock size in a single flexure. The curved pass of the central roll pair 70–76, together with the reverse flexures of the disclosed straightener provide improved means to straighten various stock sizes and materials over conventional multi-roll straighteners.

For high speed, precision straightening, twin guide rolls 206 and 208 are preferably used both at the inlet and outlet ends of the straightener, as shown in FIGS. 1 and 2. The horizontal angling and vertical adjustment of the twin rolls is similar to that previously described for the lower, central adjusting screw as shown in FIGS. 2 and 5. As further shown in FIGS. 19 and 20, the angle ϵ determines the direction of the pass line of the twin rolls, while angles γ_1 and γ_2 determine the stock diameter. Twin rolls 206–208 of FIG. 8 position and guide the stock by contacting the average stock size of diameter d on the lower side of the stock at the same angle C_o as the straight pass roll-angle C.

As shown in FIGS. 20 and 21, rolls 206–208 are located side by side, but oppositely tilted by equal angles γ_1 and γ_2 with respect to a horizontal plane through a common roll transverse axis 216 parallel to the stock axis. Rollers 206 and 208 are positioned on the common transverse axis with a constant distance 2Z between their longitudinal axes and at a variable angle ϵ to the stock axis. The relative angular location of rollers 206 and 208 varies for various stock sizes d. For example, angle ϵ must be increased and angles γ_1 and γ_2 decreased for full contact with larger stock sizes. Thus the angles γ_1 and γ_2 are adjusted according to the stock size and ϵ is then adjusted according to the direction of the stock axis until it coincides with the axis of the straight roll passes between roll pairs 68–74 and 72–78. Both of these conditions are met by the adjustment mechanism shown in FIGS. 20 and 21.

As shown in FIGS. 20 and 21, twin guide rolls 206 and 208 are mounted in tiltable roller brackets 220 and 222 in one stem and support 224, which is adjustable in a vertical direction and can be turned about its vertical axis for different stock sizes. Stem and support 224 has cylindrical segments 226 and 228, in which roller brackets 220 and 222 are supported. Angles γ_1 and γ_2 are the angles of the roller's longitudinal axes with respect to a plane 234 through centerline 216. Angular cross sections of segments 236 and 238 have gear teeth 240 and 242 that are separately engaged by pinions 244 and 246.

Similar size pinions **248** and **250** engage each other at the front, as shown. By turning square **252**, pinions **248** and **250** will turn in opposite directions as will pinions **244** and **246** and angle segments **236** and **238**. Segments **236** and **238** are fastened to brackets **220** and **222** which carry rolls **206** and **208**. Vertical angles γ_1 and γ_2 decrease or increase depending on whether square **252** is turned clockwise or counterclockwise.

Centerline **216** is in a plane **234** that is parallel to the stock axis and is normally horizontal, except when the support for the stock is to be tilted. When angles γ_1 and γ_2 are to remain constant but plane **234** is to be horizontally tilted, a dowel key is inserted at keyway **254** and pinion **250** is removed after removing retaining ring **256**. Cap screws **258** must be loosened before square **252** is turned and after adjustments have been completed, again tightened against the segment washer **260**. Cap screws **258**, in each segment move in the respective slots **262** and **264** in brackets **220** and **222**. Brackets **220** and **222** are then fastened and locked in the respective segments **226** and **228** of stem and support **224**.

In an alternative embodiment, FIGS. **23** and **24** illustrate how twin guide rolls **206** and **208** and guide roll **210** can be used to position the stock at the ends of the curved pass of a single crossroll pair **266–268**. The stock is wedged by the straightening loads into angles W_o formed at the entering and exit ends of roll pair **266–268** to maintain it in the curved pass. Guide rolls **206**, **208**, and **210** tend to force the stock into the wedge angle W_o at both the inlet and outlet ends.

In accordance with the present invention, the crossroll pair **266–268** of FIGS. **23** and **24** is preferably combined with inlet and outlet supporting guide rolls. Since the larger diameter roll **268** is the female roll and the smaller diameter roll **266** is the male roll, the stock will be wedged into angles at the ends of the rolls and thus maintained in the curved pass, provided the stock is engaged throughout the pass. Therefore, as the stock enters the pass but before it becomes fully engaged, the rotational speed of the smaller roll **266** is made such that its peripheral speed is slightly higher than that of the larger roll **268**. Since the smaller diameter male roll has a higher peripheral speed than the larger diameter female roll, the stock tends to be forced into the wedge angle and is thereby maintained in the curved pass at the entry end. Conversely, the peripheral speed of the smaller roll may be made slightly lower than the peripheral speed of the larger roll as the trailing end of the stock leaves the outlet end of the curved pass so that the stock is forced into the wedge angle at the outlet end.

FIGS. **23** and **24** illustrate how the differential peripheral speed dV forces the stock into a wedge angle at the entry end of the roll pair. A full length guide **269** laterally supporting the stock as indicated by "G" will thus maintain the stock in the pass, particularly when the trailing end of the stock has passed the central portion of the curved roll pass. A drag is provided in the drive for the larger diameter roll such that the appropriate speed differential is maintained, but that will permit the rolls to turn at an equal peripheral speed when both rolls engage the stock. There are several alternatives for accomplishing this variation in the relative speed of rolls **266** and **268**.

In the first alternative as shown in FIG. **31**, a clutch **301** is provided in the drive means for the larger diameter roll and an adjustable, light brake **302** in the drive means between said clutch and the larger diameter roll. The clutch may be a magnetic clutch which is automatically disengaged as the brake is engaged. The brake causes a slight drag on the larger diameter roll, in order that the stock may be forced laterally into the wedged support formed by the stock's contacts with both rolls at the entry end of the pass. The stock, supported on the pass line, will now be driven forward in rotary motion by the smaller diameter roll's higher peripheral velocity, while the female roll is driven by frictional engagement with the stock, until an adjustable sensing device—preferably a counter of revolutions **303**—causes the brake to be disengaged and the clutch to be reengaged shortly after the leading end of the stock has traveled beyond the center of the pass.

Since both rolls normally are driven at substantially equal peripheral speeds, a sensing device mounted ahead of the roll pass entry end should be located and timed such that it will cause the clutch and brake to be disengaged and engaged, respectively, to cause the desired amount of drag on the larger diameter roll before the stock is entered into the pass. Such a timer should preferably be a counter of revolutions **301** and fractions thereof of the motor, because the stock throughput speed is almost proportional to the revolutions of the smaller diameter roll. The mentioned timer or other sensing device should further be timed such that the brake in the drive means for the larger diameter roll is disengaged and the clutch reengaged when the leading end of the stock has traveled beyond the center of the roll pass. The drive means for both rolls will now continue at normal speed until the stock is discharged at the exit end of the pass and another stock length is about to enter the machine. The sensing device causes the clutch in the drive means for the larger diameter roll to be disengaged and the brake engaged.

If it is considered important that the trailing end of the stock be held firmly in the outlet end wedged support of the roll pass, this may be accomplished by providing a clutch **304** and brake **305** in the drive means for the smaller diameter roll. Such a clutch and brake may be actuated by the trailing end of the stock. The sensor for the smaller diameter roll can be the same as for the larger diameter roll, or independant thereof. When the trailing end of the stock leaves the exit end of the pass another sensing device will automatically disengage the brake and reengage the clutch in the drive means for the smaller diameter roll, so that another stock length may be entered between the rolls at the entry end. Both of the metioned brakes may be unnecessary if the inertia of the respective rolls are sufficient to cause enough drag on the respective rolls to force the stock into the respective wedge angle.

In a second alternative as shown in FIG. **32**, both rolls may be driven through a geared differential **306** in which case the desired roll may be slowed in relation to the other by automatically applying a light braking torque to the desired roll drive. This is done until the stock's leading end has passed the center of the pass. An adjustable sensing device is used to determine when to apply the light braking torque. Since it is difficult to find the right torque it may be advisable to provide an adjustable brake **307** and **308** of the drive shafts in order to obtain a satisfactory balance in the peripheral velocities of the two rolls for feeding the stock into the entry end of the pass.

Regardless of which of the above alternatives is used, it may be advisable to use a guide **269** to support the stock in the direction G indicated in FIG. **24**. As described above, the stock is forced into the wedge angle

W_o at the entry end (not shown) of rolls **266** and **268** by means of speed differential dV, caused by the drag on the larger diameter roll. The stock supported on the pass line and the larger diameter roll will be driven by the smaller diameter roll until the mentioned sensing device disengages the brake (or brakes). During this time, both rolls will drive the stock forward in rotary motion at substantially equal peripheral speeds until the trailing end leaves the pass. As the trailing end leaves the curved pass it is held in the pass by guide **269**. The addition of guide **269** has the additional advantage that, if the stock is not maintained on the pass line, for example the stock diameter is too small for the angle contact, guide **269** will still retain the stock. Since the guide receives very little, if any, wear the material of said guide may be nylon or other material having a low coefficient of friction. A 2-roll straightener such as shown in FIGS. **23** and **24**, and described above will therefore straighten stock more efficiently at much higher throughput speeds, and at much less, guide wear, compared to a conventional 2-roll straightener.

In the 2-roll straightener of FIGS. **23** and **24**, both rolls are normally driven at substantially equal peripheral velocity, equally sharing the power required to straighten the stock, when it is fully engaged by both rolls. When the stock is thus engaged by both rolls, the smaller diameter male roll **266** will force the stock into the wedged lines of contact at both ends of the roll-pass. The wedged lines of contact are contained in angle W_o of the tangents to same as indicated for the outlet end in FIG. **24**. An end view of rolls **266** and **268** taken at the inlet end would be exactly the same; but both rolls would revolve in the opposite, clockwise, direction.

The wedged supports at both ends of the roll-pass makes it difficult to enter the stock into the pass at the entry end. Also, the trailing end of the stock may have tendency to drop out of the last portion of the pass, if the mentioned wedge support opens downwardly and the stock is not supported at the end.

For a so-called horizontal machine, where the stock is flexed in a horizontal direction, and the wedged support angle opens upwardly at the entry end, the leading end of the stock may be dropped into the first portion of the pass. For a vertical machine, however, it should be simpler to enter the stock close to the centerline of the pass.

It should be noted that to those familiar with the art, many other ways of controlling the peripheral velocity of unequal diameter rolls can be developed. For instance, International Harvester has developed a Torque Amplifier with a freewheeling feature, where a lower speed provides the freewheeling feature, while the normal speed will be had by actuating a hydraulic clutch in the planetary speed reducer.

Curved Pass Female Roll Contour

Preferably, the roll pair **70–76** forming a curved pass includes a female roll **70** having a three-section contour that includes an abruptly curved central section that tangents two outer sections. The outer sections are portions of a contour having a less abrupt curvature and a larger throat diameter than the central section. In contrast to the multi-sectional contoured rolls of the prior art, the male and female rolls of the subject invention provide a curved pass for large stock sizes as well as small stock sizes.

A female roll having a three-section contour in accordance with the subject invention is shown more specifically in FIG. **22**. Contours from points **270** to points **272** extend a length Z, along the axis and are defined by revolving a cylinder around the longitudinal axis of the roll, where the cylinder is spaced a predetermined distance and at a predetermined angle with respect to the longitudinal axis. The surface of the roll's central section **270-0-270** extends a length Z_o but has a sharper curvature. The minimum or "throat" diameter "TD" of the central section is smaller than the minimum diameter defined by extrapolating the curves defining the end contours between points **270** and **272** to the transverse axis of the roll. The end sections and the central section have the same tangents at points **270**. When straightening high strength stock, the central curved pass of the subject invention reduces dependence on small roll center-distance in a multi-roll straightener.

The outer contour of roll **70**, from points **270** to points **272** forms a concave side of the curved pass for larger sizes of stock and materials of lower strength. The central portion of the roll **70**, from point **0** to points **270**, forms the concave side of the pass for smaller sizes of high strength stock which require more abrupt flexure to stress most of the section to or beyond the yield point of the material. When the roll angle is set for the larger stock sizes and lower strength materials, a small gap of clearance over the central portion of roll **70** is left.

The difference 2dy between the throat diameters of outer contours **270–272** and the central contour **270-0-270** of roll **70** shown in FIG. **22** is relatively small. Where roll **70** is intended to straighten, size and reduce a narrow range of stock sizes at only relatively small changes in roll angles A and B, it may be preferable to omit the central contour **270-0-270**. In this case the diameter of roll **70** can be made even smaller. However, where this is done, back-up rolls **274** and **276** as shown in FIGS. **25** and **26** may be required to provide the forces necessary to flex and size the stock. Such back-up rolls may also be required for male roll **266** of FIGS. **23** and **24**.

The three section contour of female roll **70** in the curved pass of the subject invention can be used in a 2-roll curved pass straightener, a 3-roll cluster curved pass straightener or as the female roll in a central roll pair of a curved pass multi-roll straightener. The outer sections of the three section contour serve as supports for flexing stock of larger diameters, while the central section provides for more abrupt flexure of smaller diameter stock and higher strength materials. The three-sectional contour for the female roll is advantageous in that the variations required in the roll angles of the opposed working rolls for various stock sizes and materials are substantially lower than in the prior art. Thus, the range of bar and tube sizes and materials that the cross-roll straightener can accomodate is significantly increased.

FIGS. **27**, **28** and **29** show three-section female roll **267**, of a contour similar to roll **70**, but of relatively larger diameter described herein as used in combination with a twin roll bending yoke **278** and **280** to form a curved pass three-roll cluster. The three-section contour of female roll **267** substantially increases the flexure capacity of the 3-roll pass comprised of rolls **267**, **278** and **280**. As shown in FIG. **29**, the twin male rolls **278** and **280** each have a male contour half **282** and **284** and a straight, cylindrical half **283** and **285**. Twin rolls **278** and **280** are not symmetrical about their transverse axes **286**; but are inversely symmetrical in relation to each other and to the stock pass. The stock is flexed into wedge angles W_F and W_N by the male rolls. Alternatively, the cylinder portions 283 and 285 may have a concave contour, less abrupt than bending portions 282 and 284.

The male contour portions 282 and 284 of the bending rolls produce a resultant load P that produces reactions V_N and H_N at the near end of the curved pass and V_F and H_F at the opposite end of the curved pass. The bending load forces the stock "S" into wedge angles W_N and W_F at opposite ends of the curved pass between the ends of the female roll 267 and the male contour end of each male roll 278 and 280 as shown in FIGS. 27–29.

Rolls 278 and 280 can be mounted in tiltable brackets similar to that for guide rolls 206 and 208 as shown in FIGS. 20 and 21 having a common support. Rolls 278 and 280 can thereby be vertically adjusted with respect to the stock and are angularly adjustable about a common support centerline. In addition, the vertical angle of rolls 278 and 280 with respect to a horizontal plane can also be adjusted to produce appropriate contact with the stock as it is flexed in the curved pass. As well as forming the bending yoke in a single 3-roll curved pass cluster, a bending yoke comprised of rolls 278 and 280 can also be used between inlet and outlet cross-roll pairs or between conventional three-roll clusters.

FIG. 30 shows a bending roll having an even broader operating range than the 3-section working roll of FIG. 22. The bending roll of FIG. 30 has a 5-section roll contour especially suited for straightening a large variety of stock sizes and materials. The contour of the female roll shown in FIG. 30 includes a concave central section 288 that is symmetrical about the roll centerline and the transverse axis and that has a throat diameter TD_1. The roll contour further includes a first pair of symmetrically arranged conical frustrums 290 and 292 that tangent the central section at their small ends. The conical frustrums support smaller diameter stock and stock of high material strength as it is flexed into the central section by the male roll. Conical frustrums 290 and 292 make it possible to flex and straighten relatively much smaller stock sizes than with conventional female rolls by substantially increasing the capacity of the female roll to support smaller, more abruptly flexed stock sizes. The roll contour further includes a second pair of symmetrical sections 294 and 296 that tangent the conical frustrums 290 and 292 at their large ends. Symmetrical sections 294 and 296 are portions of a concave contour defined by a cylinder disposed at a distance of $\frac{1}{2}$ $TD+\delta$ from the center axis and inclined at a selected angle with respect to the roll axis. Outer sections 294 and 296 have a less abrupt contour than central section 288 to support and straighten larger stock sizes in a curved pass. The throat diameter of the concave roll contour is larger than that of the central section by $2\ \delta$.

The contour of the disclosed female roll is such that excessive slippage between the rolls and the stock is avoided over a broad range of stock sizes and material strengths. Specifically, the roll angle adjustment of the female roll is substantially the same as the roll angle adjustment for the male roll for different stock sizes and material strengths such that the contact angles of the opposed rolls with the stock is substantially the same.

Also advantageously, the central section of the female roll can be used to round up and size the stock when used in combination with a male roll of suitable contour for compressing the stock. The preferred length at which the stock is compressed is a length that covers the entire surface of the stock as it is rotatingly advanced through the machine. Where sizing and rounding of the stock is not required, the length of central section 288 can be made substantially smaller such that high strength stock of extremely small diameter can be flexed and straightened.

The female roll contours shown in FIGS. 22 and 30 are further preferable for 3-roll single clusters, such as shown in FIG. 27, and especially for the basically 2-roll straightener of the curved pass FIG. 23, where the female roll is of generally larger diameter than the opposed male rolls or roll, respectively; inasmuch as for such opposed rolls it is simpler to calculate the approximate optimum proportion of the larger end diameter to the throat diameter of the opposed female and male rolls. Such proportions should be near the same, where the opposed rolls contact the stock.

Similar to the 3-section female roll of FIG. 22, the 5-section roll of FIG. 30 can be used as the female roll in any curved pass cross-roll straightener including 2-roll straighteners having a concave female roll opposed by a concave, straight cylindrical, modified cylindrical, or convex roll or with a bending yoke of an opposed pair of asymmetrically mounted male rolls.

In an alternative application for flexing stock, separate controls may be provided for the individual operation of the double acting cylinder 128, FIG. 2. The hollow piston 124 supports the lower adjusting screw 122 and may be used to flex the stock by hydraulic pressure, where operating the screw handwheel and drive cannot produce the force required. Thus, if in setting up the machine, a straight piece of round stock of a certain diameter contacts all rolls 68 to 78, inclusive, and a tube of the same diameter is inserted into the machine in order to straighten same, it must be flexed over roll 76 and contact roll 70. Roll 70 is, therefore, first backed off from the tube a desired amount for flexing the stock. Screw 122 is unscrewed by the same amount in screwbox and yoke 146 while low hydraulic pressure is entered on the upper side of hollow piston 124, thereby keeping roll 76 in the original position. The pressure is now reversed in the hydraulic cylinder forcing the hollow piston, its adjusting screw and attached roll 76, to flex the stock against roll 70. If the amount of flexure is sufficient to stress the stock material slightly beyond its yield point, in the outer fibres of the stock, the rolls may be rotated to feed the stock through the machine thereby straightening the same, and other lengths of stock may be entered into the machine, to be continually flexed and straightened.

It should be noted that roll 70 may be backed off simultaneously with the mentioned hydraulic cylinder moving the hollow piston, its adjusting screw and the attached roll 76, at a slightly higher nominal speed than roll 70; thereby flexing the stock against roll 70 at a speed controlled by the speed of the latter. The advantage of such a procedure is that the stock will be held between rolls 70 and 76 while it is being flexed.

Similarly, in any type of rolling mill apparatus where elongated stock is fed and/or reduced under pressure between rotating rolls, one roll may be automatically retracted to by-pass an obstruction, such as an upset end, a spliced or welded joint of continuously processed stock, and then automatically be brought to bear on the stock at the same pressure and the same adjusted pass opening as previously, by means of sensing devices that control the double acting cylinder backing the adjusting screw, its yoke and roll.

Another alternative embodiment of the invention is an improvement on the conventional 7-roll straightener having two 3-roll end clusters and an intermediate single bending roll, which flexes the stock against a driven, bottom roll in each cluster. The straight pass twin guide rolls may be adjustably arranged opposite the single bending roll to guide the flexed stock under the bending roll into the leaving end pass. Such a pair of adjustable, straight pass, twin rolls provide necessary guidance particularly for smaller stock sizes and upset end tubing. Such twin rolls could also be backed by a double stroke cylinder, similar to the central, lower adjusting screw of FIG. 2. If so, the central cluster could normally contact the main diameter of the tubing and automatically be opened, by retracting the twin guide rolls, for the upset end of the tube to pass, and then automatically close down to normal pass opening, by having sensing devices activating the twin roll backed double acting cylinder.

Still another use of the twin guide rolls would be entering and leaving tables for cross-roll straighteners, piercing mills, reelers, sizing mills and the like.

While certain presently preferred embodiments of the invention have been shown and described and presently preferred methods of practicing the invention have been illustrated, the invention is not limited thereto but may be otherwise variously embodied and practiced within the scope of the following claims.

I claim:

1. A method for maintaining stock in a curved pass of a cross-roll straightener having a female roll of larger diameter than an opposed male roll, both of which are normally driven at substantially equal peripheral speeds, said method comprising:

temporarily rotating the smaller male roll at a higher peripheral velocity than the female roll such that the surface speed of the male roll is greater than the surface speed of the female roll and the female roll is driven by engagement with the stock as it enters the roll pass;

driving the female roll by a drive means when the stock has traveled beyond the center of the pass such that the surface speed of the male and female rolls are substantially the same; and

sensing the leading end of the stock and causing a temporary drag on the female roll when the stock is being entered into the pass between said rolls.

2. A method for maintaining stock in a curved pass of a cross-roll straightener as described in claim 1 further comprising:

a clutch and a brake in a drive means for the larger diameter roll; and

a sensing device located near the entry end of the roll pass activated by the leading end of the stock to release said clutch and said brake applying a slight braking torque to the large female roll thereby causing a temporary drag on said roll to decelerate its peripheral speed in relation to that of the male roll; thus forcing the stock into angularly wedged stock supports at the entry end of the pass; said stock being driven by the smaller diameter roll and in turn the stock drives the larger diameter roll by frictional engagement until a timer connected to said sensing device releases the brake and engages the clutch when the stock has traveled beyond the center of the pass; thereby driving both rolls at substantially equal peripheral speeds until the trailing end of the stock leaves the pass and another stock length activates the sensing device as it enters the pass.

3. A method for maintaining stock in a curved pass of a cross-roll straightener as described in claim 1 further comprising:

a differential drive means geared to normally drive the male and female rolls at substantially equal peripheral speeds equally sharing the power required to drive the stock forward in rotary motion;

a brake in the drive means for at least the larger diameter roll;

a sensing device located ahead of the entry end of the roll-pass activated by the leading end of the stock to actuate a slight braking torque to the larger diameter roll causing a temporary drag on said roll and increasing the relative peripheral velocity of the smaller diameter roll thereby forcing the stock into angularly wedged stock supports at the entry end of the pass, such that the two rolls will move the stock forward in rotary motion; and

a timer in conjunction with said sensing device such that the brake in the drive for the larger diameter roll will be disengaged when the leading end of the stock has traveled beyond the center of the roll pass; the differential will now drive both rolls at substantially equal peripheral speeds until the stock is discharged at the exit end of the pass and another stock length is about to enter the entry end of the roll pass.

4. A method for maintaining stock in a curved pass of a cross-roll straightener as described in claim 1 further comprising:

an adjustable guide laterally disposed on a near side of angularly wedged stock supports at the entry end of the pass, substantially parallel to the pass line of said male and female rolls such that the guide maintains the stock in the roll pass as it passes between the male and female rolls.

5. The method as described in claim 1 further comprising:

providing additional guidance in the straightener by having a pair of outboard roll supports that force the stock into roll wedge-angles at each end of said cross-rolls.

6. A cross-roll straightener comprising:

a pair of opposed rolls having a smaller diameter roll and a larged diameter roll forming a curved pass for flexing stock;

drive means normally rotating said rolls at substantially equal peripheral speeds;

a means for slowing the peripheral speed of said larger diameter roll in relation to that of the smaller diameter roll while stock is entering into the pass between said rolls, said means being such that the larger diameter roll is free to rotate at the speed imparted to it by the stock when both rolls are in engagement with said stock;

a means for driving the larger diameter roll after the stock has entered the pass, such that both rolls drive the stock at substantially equal peripheral speeds;

a means for slowing the peripheral speed of the smaller diameter roll when the trailing end of the stock is in the roll pass; and

means for allowing both rolls to be driven at normal substantially equal peripheral speeds after the trailing end of the stock has been discharged at the exit end of the pass.

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